

**MECHANICAL PROPERTIES AND CHARACTERISTICS OF YOUNG TEAK
FROM THE THINNING FOR MAKING PRODUCTS**

Case Study: Young Teak from the Teak Plantation in West Java Area, Indonesia

July 2015

IMAM DAMAR DJATI
Graduate School of Engineering
CHIBA UNIVERSITY

(千葉大学学位申請論文)

製品を製造するための間伐の若いチーク材の機械的性質と特性
ケーススタディ：インドネシア西ジャワ地区のチークプラン
テーションにおいて間伐される若いチーク材の有効利用への提
案

2015 年 07 月

千葉大学大学院工学研究科
デザイン科学専攻
イマム ダマル ジャティ

A thesis submitted to
Graduate School of Engineering
Chiba University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

ACKNOWLEDGEMENTS

Being in the Design Morphology Unit - Chiba University definitely has provided a new area for me to explore and obtain the best chance to venture outside my previous zone. The integrating knowledge, especially wood as material, have given me the valuable experiences, even widening my perspective on how to conduct more researches within the engineering, science, and design boundaries. During the four years of time that I have spent in the Design Morphology Unit is the splendid and valuable experience. It is indeed a fascinating joyride, because I can do the research on my favorite topic of Teak especially, as one of the prominent and important wood species in my country, Indonesia.

Therefore, first and foremost, I would like to express my sincere and deepest gratitude to Prof. Dr.Eng. Mitsunori KUBO. Without his consent and support, there is no way I could begin this fascinating journey. My heartfelt thanks also is given to Assoc. Prof. Takatoshi TAUCHI, and Prof. Dr. Eng. Fumio TERAUCHI. Their continuous guidance and supervision have put me through various study's obstacles from the start until the end of my study. They have helped and supported me to open another perspective in my research horizon. My deep appreciation also is dedicated to Prof. Dr.Eng. Makoto WATANABE, without his great effort, I could not get a great chance to continue my doctoral study in Chiba University especially.

I also would like to express my gratitude to the Japan International Cooperation Agency (JICA), Ministry of Education and Culture - Republic of Indonesia, and Asia SEED, since without their support in the scholarship; I would not be able to pursue and complete this study. In this opportunity I would extend my gratitude to Faculty of Art

and Design (FSRD) of Bandung Institute of Technology (ITB) who has provided me with great support and permission to take a study abroad in Japan, to the Dean of FSRD, Dr. Imam Santosa, M.Sn, and the Vice Dean Dr. Achmad Syarief, MSD., and also Dr. Nuning Damayanti, Dipl. Art.

My gratitude also goes to my colleagues in the Product Design Department - FSRD - ITB. A special thanks is dedicated to Dr. Dudy Wiyancoko, for his great encouragement. My gratitude also goes to Mrs. Refinda, S.T, M.T and the staffs of Civil Engineering Laboratory - ITB, for supporting tools and its facilities. My gratitude thanks also to Mr. Ir. Oemar Handojo, M.Sn, for his persistence to me during the counseling of engineering aspects at the early stage of this research in particularly.

I also benefited to other fellow Ph.D. candidates of ISKT, for the countless debates and discussions, exchanging ideas and thoughts of which enrich the research and study process. Therefore, many heartfelt thanks to Takanobu YAKUBO, Yukiko KITAMURA. My gratitude also goes to my friends and colleagues: Emika OKUMURA, Kyohei OKADA, Slamet "Didi" Riyadi, Dr. Ilham Alimuddin, Mr. Bambang Setiadi, Dr. Sulfikar Amir, MA., Novalia-chan for translation, and also to many other whom I could not mention for their various support during the course of my study. Gratitude thanks also for my Japanese teachers in CIRE-Chiba University, Mrs, Shiraishi sensei, Mrs. Sato sensei, Mr. Holda sensei, and to Prof. Dr. Tetsuya Kato, for involving me in his research during my study.

Many thanks is pledged to PPI-Chiba and its members, and Chiba-Indonesia Society (Ibu Kawanami and friends), for their generous friendship and warmhearted supporting during my staying in Chiba especially.

To my lovely family, in Bandung, whom gave me their relentlessly support through prayers and attentions, this thesis is wholehearted dedicated for them too, to my father (Abah) and my mother (Umi), for my father in law (Ayah-Alm) and my mother in law (Ibu). Most importantly, I would like to dedicate this thesis to my lovely wife, Lia Faridah, our lovely eldest son, Naufan ALPHA Hariz, our lovely daughter, Ridha BETA Zahra, and our lovely youngest son, Reza GAMMA Azka, for their patience, continuous moral support and unconditional love through out the completion of my study, almost for 4 years abroad and far away from them.

Imam Damar Djati

Chiba, September 2015

Design Morphology Unit, Department of Design Science,

Graduate School of Engineering, Chiba University.

SUMMARY IN JAPANESE

木材の需要は増加しているが、供給は逆に制限され、この需要を満たすために貢献できる間伐からの潜在的な若いチーク材 (*Tectona grandis* L.f.) の量がある。植樹から収穫までの時間の間に（回転歳）、辺材含む若いチーク材の木の数に残りのチーク材の木がより良い成長を刺激するために間伐で定期的に伐採されている。一つのチーク植林地の中で、一ヘクタールの平均品質サイトと40年の回転年齢に、収穫の際には277の39歳のチーク材の木が残るまで1769の5歳のチーク材の木が回転時代中に定期的に伐採される。世界で二番目の大きいチーク植林面積として、インドネシアのジャワ島にチーク植林地は少なくとも120万ヘクタールがあり、および、他の国には31万46千ヘクタールがある。本研究では、インドネシアの西ジャワエリア植林地の40年の回転年齢の各年齢クラスの辺材の機械的性質、特性、そしてその若いチーク材の心材部分を評価した。若いチーク材の機械的性質は年齢クラス間で辺材とその心材部分の違いの強さは重要ではないので、基本的に若いチークは成熟したチークと同様に利用することが可能である。若いチークの特性は辺材とその心材部の間に様々なボーダーパターンと色強度の違いに意図されており、したがって、若いチーク材の用途では、辺材の明るい色がその心材部に比べると着色剤の色がより魅力的に表示され、辺材と心材部との間のコントラストの境界線パターンの組み合わせはユニークな外観を作る。間伐から若いチークかなりの量は潜在的な木材ので最適な製品に利用することが必要であり、その製品の価値を高めるために、その特性および顕著な特性を生かす。

ABSTRACT

The demand of wood is increasing, but the supply is limited, on the contrary, there are amount of potential young teaks (*Tectona grandis* L.f.) from the thinning that can contribute to meet this demand. During the time from planting until harvesting (rotation age), a number of young teak trees, which comprise mostly sapwood, are felled regularly due to the thinning to stimulate the better growth of the remaining teak trees in the plantations, e.g., in one of the teak plantations, for 1 hectare with the average site quality and the rotation age of 40 years, from 1,769 5-year-old teak trees will be felled regularly during the rotation age until 277 39-year-old teak trees remain at harvesting. There are at least 1.2 million hectares of teak plantations in Java Island, Indonesia, as the second largest teak plantation area in a country in the world, and 3.146 million hectares in other countries. This research has assessed the mechanical properties and the characteristics of sapwood and its heartwood part of young teaks from each of age classes in the rotation age of 40 years of teaks plantation in West Java area, Indonesia. Mechanical properties of young teak has been determined that the difference strength between sapwood and its heartwood part among the age classes is not significant, and therefore basically young teaks is possible to be utilized as well as the mature teaks. The characteristics of young teak are intended to the various border patterns and the different of color intensity between sapwood and its heartwood part. Lighter color of sapwood has the specific effect that the color of colorant will appear more attractive than on its heartwood part, and the combination of the contrast border patterns can be categorized in various configurations that will create the unique appearances for making products. Significant amount of young teaks from the thinning is the potential wood material that necessary to be utilized became the most suitable products by taking the advantage of its properties and prominent characteristics to enhance their values.

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LIST OF ABBREVIATION AND TERMS

$^{\circ}\text{C}$	"degree Celsius"; unit scale of measurement for temperature.
AC	Age Class (range of age every ten years)
ASTM	American Society for Testing and Materials.
FAO	Food and Agriculture Organization; one of the world organization as an agency of the United Nation.
FSW	Forest Stewardship Council; an independent, non-governmental, and non-profit organization.
GPa	Giga Pascal (10^9); unit of pressure in metric system; force per width square.
HW	heartwood (inner part in the wood trunk).
kgf/s	kilogram force/second; number of load/force per second; equal to N/s.
klx	kilo lux; unit for luminous power incident on a surface.
L.f.	Linnaeus filial; standard botanical author abbreviation; refers to Carolus Linnaeus (Carl von Linne, Swedish botanist).
MC	moisture content
MOE	modulus of elasticity
MOR	modulus of rupture
MPa	Mega Pascal (10^6); unit of pressure in metric system; force per width square.
N	Newton; unit of force in metric system.
N/s	Newton/second; a number of load/force per second; equal to kgf/s.
SNI	Standar Nasional Indonesia
SW	sapwood (outer part in the wood trunk)

UTM universal testing machine

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CHAPTER 1

INTRODUCTION

1.1 Background

One of the experienced inspirations of this research when the numbers of teak (*Tectona grandis*, L.f.) that is categorized as young teaks, have been laid on the ground without any protection from the exposed various weather and destroyed conditions. These young teaks have been gained especially from the thinning process of the teak plantations area.

After the certain time, because of this poor laying relatively, the young teaks especially, which mostly comprise is still *sapwood* part, will be decayed by the wood-destroying fungi or by the destroyer insects, and then those teaks became decrease its value.



Figure 1.1. Logs yard, area for temporary storage of teak trunks after felling, in one of the teak plantations in West Java area, Indonesia.

From that previous point above, the interest and curiosity are begun to consider and how to utilize this potential material optimally, and in this case, the main focus is intended to the young teaks which are obtained from the thinning process in the teak plantation in particular because of its quantity.

At the present, there are at least 1.2 million hectares of teak plantations only in Java Island, Indonesia, as the second largest teak plantation area in a country in the world, and 3.146 million hectares in other countries. This amount is not included the spread of teaks which are existed in another island and area in Indonesia. In the teak plantation in Java Island, e.g., in one of the certain teak plantations, for 1 hectare with the average site quality and the rotation age of 40 years, from 1,769 5-year-old teak trees will be felled regularly during the rotation age until 277 39-year-old teak trees remain at harvesting.



Figure 1.2. Temporary storage area for young teak trunks in one of the wooden product industries in Central Java area, Indonesia.

Although the amount of young teak material that is obtained from the thinning is available in the large number, but these material is recognized as a low value in the market relatively, but actually if these material can be developed and to be utilized according to the *properties* and its *characteristics*, and it is to be hoped that from this could be increased its commercial value, especially if consider to the need of wood material is always increased from time to time, but on the other hand the sources of wood material are becoming limited relatively because of the decreasing of its sources area, both from the natural forest and the wood plantation in particular.

Utilization of young teak will need the basic information about mechanical properties and its characteristics for optimizing of their utilization, but unfortunately in this case, characteristics and mechanical properties data about teak usually refers only to the old-growth teak (*mature teak*). The data of young teak which refers to the young teak from the certain age classes specifically are rare or possibly there is not yet available, and for this reason, assessment and determination to the characteristics and properties of young teak (*juvenile teak*), both *heartwood* and its *sapwood* part, is necessary to be conducted directly from the research.

Young teak is different from the mature teak, both sapwood and its heartwood part of young teak are still considerable amount, or even comprise mostly sapwood. These two part, sapwood and its heartwood are should be considered for its properties separately. Although some references and have mentioned about the similarity of the strength (*mechanical properties*) between sapwood and its heartwood, but this information is general, it is not exactly refers to the wood in the *tropical* or *temperate/sub-tropical* area,

and it is not inform specifically to the *hardwood* (*deciduous, angiosperm*) or *softwood* (*conifers, gymnosperm*). Teak is one of the hardwood species from the tropical area.

The question regarding to this research especially about young teak from the thinning, how about the specific properties and characteristic of young teaks, and the influence to the utilization become the most suitable various products according to its properties and mechanical properties.

1.2 Objectives of the Research

The aims of this research are to describe the potential of wood raw material, e.g. young teak from the thinning, and the possibility of its utilization for making various products, which is based on its distinctive characteristics and mechanical properties, and therefore this study assess and determines the properties and characteristics of young teak from West Java area especially as a case study for the next step in utilization.

The objective of this research also is to provide the new horizon about the advantages of young teak especially, which is recognized has the low value relatively before, by utilize its unique characteristics for enhance their values.

1.3 Methods and the Approaches of the Research

To understand about teak, the first aspect that should be understood is about wood in general and the relation to the important and strategic of its existence in the need of material for many occupations in this modern era.

Primary and secondary data about young teak properties and characteristics are used in this research especially. Description about wood in general is provided by the secondary data, but for young teak as a case study in this research, the main data is the primary data that is based upon the field research directly to the teak plantation and assessment of mechanical properties and its characteristics in the laboratory and workshop in which use teak trees and its specimens. For the basic information and comparison aspects, secondary data are obtained from the various literatures, such as books, published papers, technical guidance, etc., both available in printed documents and online.

This research conducts of assessment for obtain the *modulus of elasticity* (MOE) and the *modulus of rupture* (MOR) of young teak of 40 year-old duration age. Three young teak trees are felled and then those are made to the standardized specimen according to the combination of *American Society for Testing and Materials* (ASTM) and *Standar Nasional Indonesia* (SNI). For the basic information about mechanical properties of young teak, the data is assessed from MOE and its MOR, which are determined in a static three-point bending test until the specimens reach to the breaking/rupture condition. For the completed and the combination in practical application, the tests are added also by the natural cleavage and the bonding cleavage properties. The data that drive from the *universal testing machine* (UTM) are calculated for getting the MOE and MOR as the components of mechanical properties of young teak (specimen) in this research.

1. 4 Conclusions and the Outcomes of the Research

From this research, one of the aspects that can be concluded about the young teak as the potential material in which can be utilized with taking its distinguished properties and the

prominent characteristics that has been identified and developed in this research both theoretically and practically.

The result of determination for the mechanical properties has shown that the young teak has the same strength class with mature teak and therefore basically it is possible to utilize this young teak for the ordinary application as well as the mature teak, but on the other hand, due to the trunk size of young teak that is narrower than the mature teak relatively, therefore the application of young teak should consider for the suitable products according to its limited size or to enlarge the size of young teak, and therefore in this case, development of new or distinctive wood joint system is necessary to be done in another research which is focused in this occasion.

The characteristics of young teak are intended to the various border patterns between sapwood and its heartwood part, and the different of the color intensity. In practical application of young teak, the lighter color of sapwood has the specific effect that the color of colorant will appear more attractive than on its heartwood part, and the combination of the contrast border-patterns between sapwood and its heartwood part will create the unique appearances. This various border patterns has been identified and created into new terms in relation to the practical application. The numbers of new developed *border-patterns configuration* are having unique appearances and can be explored for its utilization become various products by taking the advantages of those prominent characteristics, such as for parquet-flooring, panels, components and parts of furniture and building, various wooden products, et cetera, both of functional and non-functional/decorative products.

Finally, the outcome of this research is to be hoped that can stimulate the utilization of relative low value of young teak, and afterward can provide stimulate to increase the job opportunity (provide) of production process that use young teak, for young generation (productive age) in particular, as an effect of demographic bonus in Indonesia at present and in the future ahead. It is a kind of giving the added value to the raw material and encouraging to the social-economy multiple effects relatively.

1.5 Organization of the Thesis

This thesis is divided into 3 main parts although the contents are composed in six chapters. The first main part is the explanation about wood in general as the natural material, and the second part describes about teak and the young teak especially in West Java area, Indonesia, and then the last part is the description and explanation about the conceptual approaches and the practical application of young teak become products.

At the part of practical application, there are the numbers of figures in which describe about *border-patterns configuration* and its new developed terms for recognizing occasion. The figures of configuration application into product are also completed appropriately for giving the ease visual description related to its new developed terms.

At the end of this thesis part, there are several recommendations or suggestions for the next/future research that is to be hoped can do by another researcher according to its related experts as the continuity of the previous research for getting the optimum solutions and results.

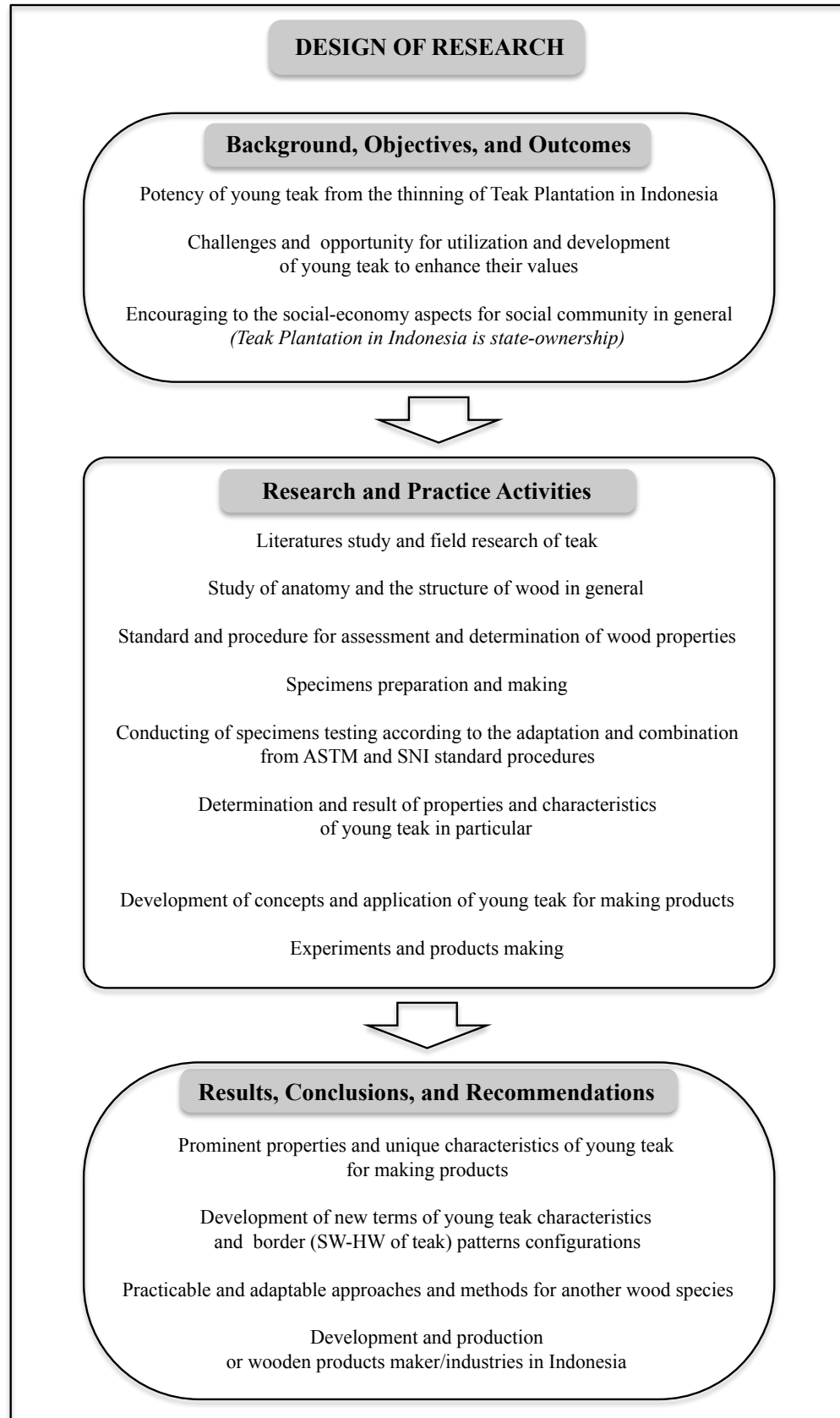


Figure 1.3. Design of the research

CHAPTER II

WOOD AS NATURAL MATERIAL

Term of wood in dictionaries usually refers to the general understanding about the hard fibrous and porous material that forms trunk or branches of the tree. Wood has played a prominent role in human life throughout history. Wood has been used and adapted since the earliest recognition. From the early age, the use of wood considered the quality, cost and availability, as well as the intended use. As a natural material, the unique nature of wood has been gradually understood by experiences and more recently by the systematic research and the scientific observations. Wood is still essential for human life, and has evolved from a simple natural material to a modern industrial and engineering material, with unique ability to contribute to the human life both as material for use and as an important element in the natural world [1, 2].

The unique characteristics and abundance of wood has made wood to become natural material for various utilizations such as structure of buildings and homes, furniture, tools, decorative objects, and many other products. Consequently, wood is prized for the multitude of application [3].

Wood has been used and continued to increase as part of the general world trend toward the increase use of wood. Recently, much of wood use has taken different forms, reflecting the new product demands and new technologies. Among the competitions and advancement of technologies from artificial materials such as metals, plastics, cement, and other new materials, wood has maintained a place in most of its traditional roles, and its

serviceability is expanding through the new uses [4]. Wood has been the most versatile element and useful construction material and it is still used more than any other construction materials. Recently, wood is still remained as the most widely used in those occasions [2].

In construction sector, the professionals have become increasingly interested in the environmental impacts of construction material. Preference for wood products has increased as wood has been recognized as an excellent choice regarding to its environmental aspects. An environmental study has conducted to compare the environmental impact of constructing a house using wood framing, steel, and concrete, and the result has shown that the design house built by wood construction has fewer negative impacts to the environment [5].

Wood is renewable material, which is the most important point regarding to the wood uses. Unlike fossil fuels, metals, and plastics, wood can be harvested and regrown. As long as wood that is harvested is replaced with new plantings in well manage and sustainable manner, this cycle can continue indefinitely [6]. Additionally, wood is still an important fuel in many countries. The Food and Agriculture Organization (FAO) of the United Nations, reports that combustible renewable and waste account for approximately 10 percent of the world's energy production. This includes the burning of wood for energy by households in developing countries and wood used in developed countries, such as Europe, in efforts to comply with the energy policy targets [7].

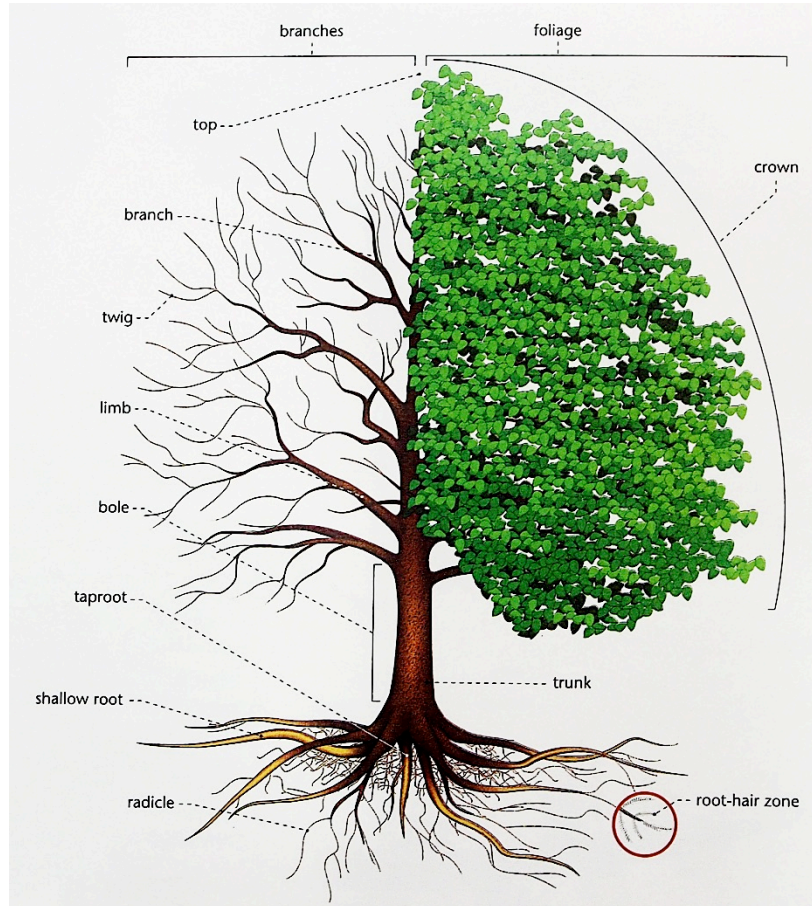


Figure 2.1. The structure of a tree [8].

Wood is available in various color and grain patterns. The unique characteristics of wood as material are important aspect in design of quality products. Many products have been and are still made of wood. Wood is still favorite choice also for many designers when making various products, e.g. furniture especially. In a book about "Japanese chairs", the author selected a number of representative and high quality chairs from the points of styles, appearances, and its functional aspects. There are 41 models of chairs which created by famous designers, and from that number at least 36 of those chairs used wood as the main material, both for structures and cushion. In this case, wood has shown in which as the material for making product is very companion for many designers [9, 10], and also is very prominent because of properties and its characteristics.

2.1 Properties and Characteristics of Wood

Wood is a natural product of the growth of the tree. It is basically fibrous. These fibrous cells and their arrangement in the tree have strongly effect to its *properties* and *characteristics* of the wood. Each type of wood has the specific *properties*. The *physical properties* include specific gravity, shrinkage, conductivity, and moisture content. The *mechanical properties*, which refer to the ability of forces resistance, include bending strength, crushing, tensile, shearing, stiffness, toughness, hardness, flexibility and cleavability. Related to the suitability of wood for manufacturing, *chemical properties* and *manufacturing properties* such as durability, workability, cleavability, and difficulty of seasoning, preserving, and finishing are also considered [11]. The mechanical properties of a wood can indicate the strength of its wood, e.g., *modulus of elasticity* (MOE), as one of the indicators for recognize the *stiffness* of a wood, has the standard average for wood at 11 until 16 GPa [12].

All wood comprises the major components of woody biomass, i.e. *cellulose*, *lignin*, *hemicellulose*, and minor amounts of *extractive* materials contained in a cellular structure [5]. Variation in characteristics and proportions of these components and differences in its cellular structures make wood become heavy or light, stiff or flexible, and hard or soft. The overall composition will influence also to the *characteristics* of the wood, such as color, texture, grain pattern, and odor. Wood has the unique properties and characteristics if it is compared to the others material, i.e., metal and plastics, which is produced by molding process, and therefore these materials have the same strength for its every direction. Wood as a natural material in which composed of fibers with a certain direction, has the different strength for each its direction. As the *orthotropic* material with three

symmetric axes perpendicularly, wood has the *anisotropic* character. This character means that the structure of wood has made the properties of wood is vary in its different direction. Therefore in general, because of anisotropic character, wood is usually stronger when the loads with the direction are applied parallel to the grain than applied with the direction at perpendicular to the grain of its wood [13].

Properties of wood have been developed and more various from time to time regarding to the more specific of its utilization. The physical and mechanical properties of wood increase, from the very common and simple, to the more sophisticated and complex. Newly recognized properties for wood include *thermal properties*, *electrical*, *friction*, and *nuclear radiation properties* [14]. Each properties and characteristics of a particular wood is important aspects to be considered for obtaining the best advantage and the most effective use of the wood in different applications and occasions.

2.2 Softwood and Hardwood

Refers to the commercially used and practical purpose, wood divided into two classifications, *Softwood* and *Hardwood*. This wood classification refers to their specific weight per unit volume (*density/gravity*) of its wood. In a rough and practical way, usually that the light one are soft and the heavy one are hard. Softwood, according to botanical group is called as *gymnosperms*, which have naked seeds, conifer leaves, and lacking vessels. This is in contrast to the *hardwood* as *angiosperms*, which have obvious vessels, flowering seed, and broad leaves. Hardwood is the diverse group that contains both the heaviest and the lightest timber that is found in nature. One of the major botanical distinctions between softwood and hardwood lies in the structures of their wood. In

softwood, the cells that serve to transport water or sap also provide mechanical support for the stem; however, in hardwood, some cells specialize in water transport, and others specialize in mechanical support. The cells that transport water are called vessels in hardwoods, and are commonly very much larger in diameter than the cells called *tracheids* in softwood. The vessels can be seen clearly as a number of pinholes on the transverse surface of wood. As a result, hardwood is commonly referred to as *porous* wood, and softwood is referred to as *nonporous* wood [11, 15, 16].

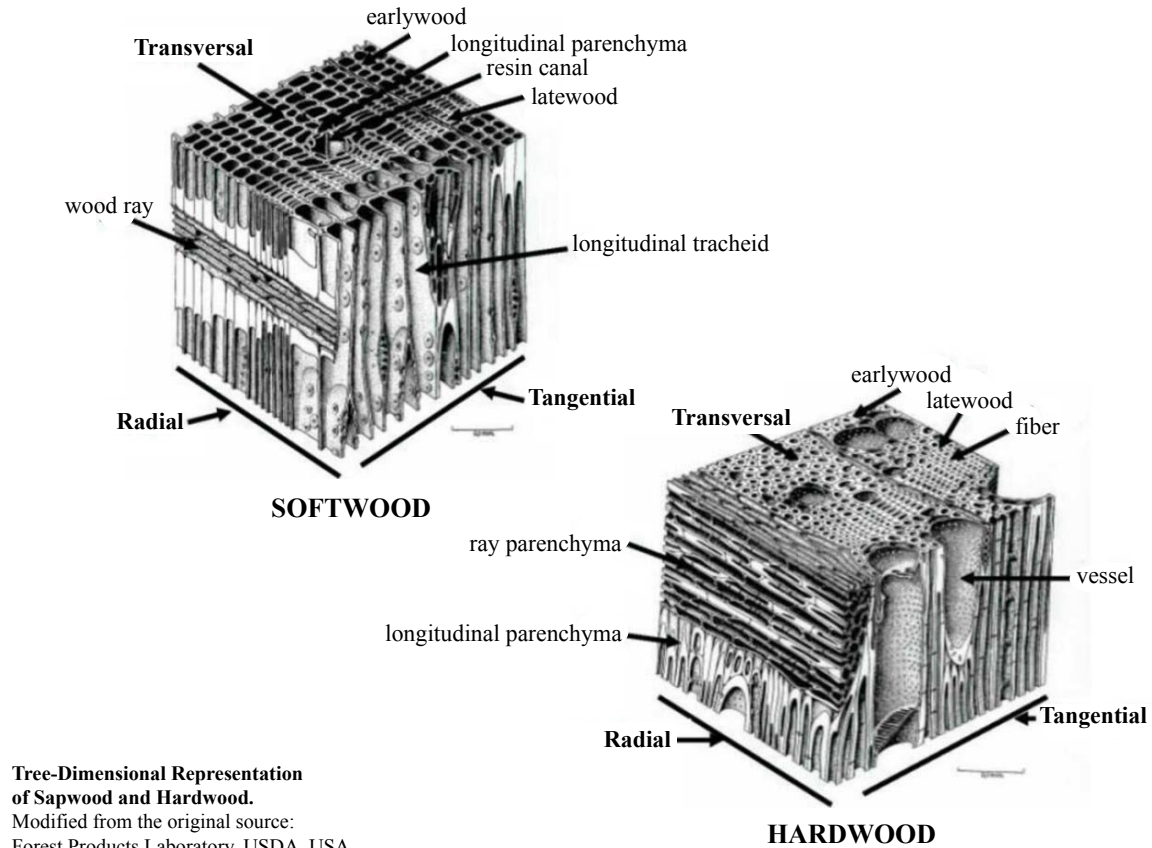


Figure 2.2. The structure of hardwood and softwood [2].

For commercial use and practical purposes, usually the lighter wood is softwood and the heavier wood is hardwood. This refers to their specific weight per unit volume of the

wood, but there are sometimes exceptions to this classification. Therefore these terms of hardwood and softwood are not indicative of the actual hardness of the wood [4, 11]. These terms can be confusing, because some softwood is actually harder than some hardwood, and vice versa. These terms arise more due to differences of the wood anatomy, i.e. its *xylem*. Softwood is made up only from tracheid, whereas hardwood is more various, from fibers and vessels [17].

Table 2.1. Anatomical structure of softwood and hardwood.

Aspects	Softwood	Hardwood
Botanical Classification	gymnosperm	angiosperm
Leave Type	generally conifers (coniferous), needle-like or scale-like leaves; evergreen	generally broad leaves; deciduous or evergreen
Pore Type	nonporous (lacking pores)	porous (obvious pores)
Conduction and Transport of Water or Sap	tracheid	vessel cells (pores in transversal surface)
Mechanical Support	tracheid	fibers (wood cells)
Storage Food Reserve	living cells (longitudinal parenchyma)	living cells (ray and longitudinal parenchyma)
Reproduction Seed	naked seed; monocotyledon	flowering seed; dicotyledon

Hardwood is more tremendous in diversity, whereas softwood is very limited [17]. Hardwood trees, with a few exceptions in the temperate and semi-tropical regions, will shed their leaves in autumn or winter, and this is also the case for a few types of softwood trees. This loss of leaves called as *deciduous*, and is contrary to *evergreen*. Softwood trees are predominant in many parts of the boreal forest, and mixed with hardwood in many parts of the temperate forest. Hardwood trees are predominant in tropical and semi-

tropical forest. Most tropical wood imported to temperate countries is hardwood [2, 15]. Tropical hardwood has the prominent economic value, moderating effect on climate, preventing floods, and soil erosion [17].

2.3 Sapwood and Heartwood

A *transverse surface (cross sectional view)* of a tree trunk consists of three areas, i.e. *pith*, *xylem*, and *bark*. The pith, as a central of trunk, is usually barely visible. The xylem comprises sapwood and heartwood. The bark is differed as the *inner bark (phloem)*, which conducts of sugars, and the outer bark that serves as a protective layer to the wood. New wood and inner bark are added each year by the *cambium*, a layer of dividing cells, which is located between phloem and sapwood part [18].

Based on difference color on annual ring of wood trunk, wood divided into two groups: *Two Color*; have an obvious different color between sapwood (*outer part; lighter*) and heartwood (*inner part; darker*), and *One Color*; obscure color between sapwood and heartwood parts. But the inner part (*heartwood*) which is harder than the outer part (*sapwood*). The other type of *one color* is no heartwood in the wood trunk. This wood type composes only sapwood.

According to mechanical properties of wood, sapwood is recognized as a weaker part of the wood trunk. It is an early age of the growth wood period. During the time (*growth*), sapwood will turn into hardwood and on the other hand the percentage of heartwood will increase while percentage of sapwood will decrease. Every wood/tree species has a different growth period from the young until mature (*appropriate age for cutting*).

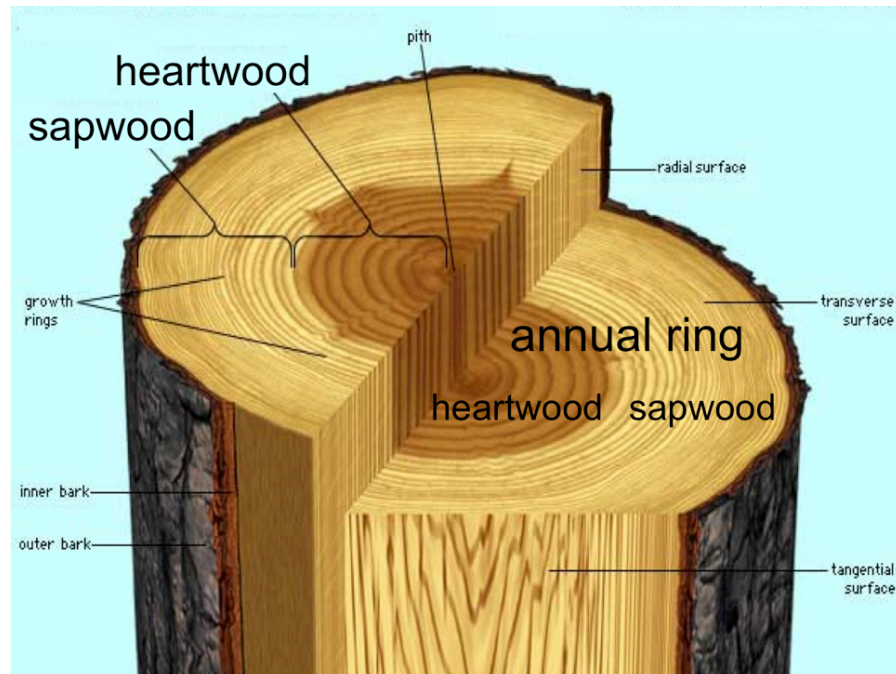


Figure 2.3. Anatomy of a wood trunk [19].

Sapwood as an outer part in the xylem contains living cells (*parenchyma*) for reserve material such as starch, as water transport, and forming the initial wood layer under the bark. New wood is added to the outside of existing wood, and the oldest wood is close to the pith. Each year that new wood is formed, and some inner sapwood loses its water transport function, and then changes become heartwood. The outer boundary of the heartwood then moves outward gradually. New wood formation and conversion of sapwood to heartwood is maintained to ensure adequate growth and survival of the tree [20].

The conversion of sapwood to heartwood is commonly associated with a color change that is due to the deposition of chemical compounds, known as extractives, in the heartwood. These extractives give the wood *durability* aspect against decay by fungi and attack by insects, such as termites, beetles, and marine borers. The color change varies among

species according to the composition of the wood. In different species, the color change between heartwood and sapwood may be slight or otherwise nonexistent [18, 20, 21].

Table 2.2. Sapwood and heartwood in the wood trunk.

Aspects	Sapwood	Heartwood
Function in living tree	living cells (parenchyma): - conduction and transport of water and sap (vessel in hardwood and tracheid in softwood); - mechanical support, by fibers in hardwood and tracheid in softwood; - storage food reserve with form of starch, produced by photosynthesis in the leaves.	no living cells, consequently: - no conducting water or food reserve and it is not essential for growth and survive; - do not give the structural support, it has provided by sapwood; - no storage for waste chemical compounds (extractives) and material surplus of photosynthesis.
Color	usually brighter than heartwood color, but not always	relatively darker, but some species has almost similar color with its sapwood
Formation	produced by cambium (a layer between phloem and sapwood)	produced from the death of parenchyma cells of sapwood
Hardness	mostly softer	mostly harder

According to some research, there is no significant difference in the *strength* between heartwood and its sapwood. This is likely because there are no differences in their structures and there is no changing anatomically. The difference in strength is closely correlated to wood density. The difference recognized only to the content of materials in their cells, which is related to wood durability [18, 20].

Under most conditions, i.e. suitable moisture and temperature, with adequate oxygen and food, the sapwood will decay more easily than the heartwood after a certain time, such as by lumberyard mold and wood-destroying fungi [22]. The lower resistance of sapwood compared to heartwood must be considered properly if sapwood part will be used for making products and, moreover, for use as structural timber, especially on exteriors that are exposed to the various weather condition.

While most softwood and hardwood have sapwood and heartwood parts, there are some species that only have sapwood. Over time, the percentage of heartwood increases while the percentage of sapwood decreases. The diameter, proportion, and thickness of the sapwood and heartwood in a wood stem vary according to the age and growth rate of the tree. The growth period from young sapling to a fully grow tree differs for every species. The properties of a wood usually reflected in its heartwood, and this part is the most significant influence and useful in terms of wood utilization [18]. In the living tree, sapwood is the most important part for growth and survival; however, after being felled and converted to be a wood log or lumber, as a material, the characteristics and properties of the heartwood become the most important aspects.

In temperate zones especially, the transverse surface, will show obvious *growth rings*, in which one ring is commonly formed each year. However, in most tropical areas, where the trees grow throughout the whole years, and consequently many tropical woods show obscure *annual rings*, while others only have zones of growth [15]. Therefore it is difficult to estimate the age of tropical hardwoods from its growth rings, such as ebony, mahogany, rosewood, teak, and other wood from tropical areas.

2.4 Appendices

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CHAPTER III

TEAK AND TEAK PLANTATION IN INDONESIA

3.1 The Prominent of Teak

Teak (*Tectona grandis* L.f.) is recognized as one of the famous and important hardwood species of the tree from the tropical areas. Wood from teaks is well known for its pleasant color, fine grain, and durability. Teak grows naturally in India, Myanmar, the Lao People's Democratic Republic, and Thailand. Teak is naturalized in Java, Indonesia, where it was likely introduced 400 to 600 years ago. Now, the teak plantations have been developed within its natural range as well as in many tropical areas of Latin America and Africa. Trial plantations have been established throughout tropical Asia, as well as in tropical Africa and in northern Australia [1].

The heartwood of teak varies from the yellow brown to the rich brown and frequently shows streaks of the dark color. These pigmented zones eventually fade with the age. The wood has coarse texture, it is usually straight-grained, and has distinct oily feel. The wood has a mild but somewhat unpleasant odor, and has the odor of leather-like when the teak is just freshly cut [2].

Teak seasons are well but rather slowly. It requires more than ordinary care in determining both the initial and final moisture contents, as variations in the drying rates of some boards are occasionally substantial. The wood is very liable to color change, but the color becomes uniform within a reasonable time after *kiln drying* (*oven-dry* seasoning). The total shrinkage of teak is exceptionally small. The shrinkage from the green, more than 12

percent moisture content, to oven-dry, the condition when the moisture content of 0 percent, is 2.5 percent for radial, 5.8 percent for tangential, and 7.0 percent for its volumetric [3, 4].



Figure 3.1. An outdoor teak product has utilized its natural weather-ability and hardness [5].

Teak is rated as very durable and resistant with respect to decay and insect attack, and extremely resistant also to the preservative treatment. Teak is somewhat variable in production processes, but can generally be worked with moderate ease by hand, e.g. wood carving uses hand chisel, etc., and also machine tools. That character is due to the presence of silica in teak. The silica content is variable, and it has been reported as being up to 1.4 percent. This silica possibly causes the dulling effect of teak on the cutting edges, and in general may be considered as appreciable. For extensive machining runs, the use of special wear-resistant steel is necessary to ensure the economical operation, e.g. the use of carbide tungsten saw-tooth blades. Teak can be finished and glued satisfactorily,

although some pre-finishing treatments may have to be considered to ensure the good bonding of finishes and glues [4, 6], and it will be influenced also by the contain of extractives in its wood.



Figure 3.2. One of the 1920's university buildings in Indonesian in which uses laminated-teak for its main construction.

Intrinsically, teak is one of the most valuable of all woods due to its unique characteristics of not causing rust or corrosion when the teak is in contact with metals; and therefore, it is extremely useful in the shipbuilding industry especially. Currently, teak is used in the construction of expensive boats, furniture, decorative objects, veneer for decorative plywood, and many other products [2, 6]. Although teak is relatively unimportant in terms of the volume of total world timber production, but because of its *strength*, *durability*, and *distinctive aesthetic* qualities, teak is still become the most tropical hardwood in demand

for a specific market of the special and the luxury applications. This is one of major importance in the forestry economies of the countries in which teak is mainly produced, e.g. Indonesia in particular [1]. The more detail about properties and characteristics of teak can be seen at the Attachment A.

3.2 The Teak Forest and the Teak Plantation

There are two type of teak forest, these called as *the natural teak forest* and *the planted teak forest* or *the teak plantation forest*. The term of teak plantation forest is usually shortened to "the teak plantation". Plantations refer to areas purposely planted and kept both for the environmental and for the commercial reasons [7]. Both area of natural teak forests and area of teak plantations have been changing during the time. The Table 3.1 shown that the number of teak plantations has increased over the last 30 years, from 1.3 million hectares in 1976/1979 to 4.346 million hectares in 2010. This area is dominated (76.9 percent) by the teaks of 0 - 20-year-old. On the other hand, the total areas of the natural teak forests slightly decreased from 29.420 million hectares in 1976/1979 become 29.035 million hectares in 2010.

Table 3.1 Total areas of natural teak forests and teak plantations, based on FAO report in 2010 [8].

Type of Teak Area	1976/1979 (1000 hectares)	2010 (1000 hectares)
Natural Teak Forest	29,420	29,035
Teak Plantation	1,300	4,346
Total	30,720	33,381

The data for area of teak plantations in Indonesia was reported to FAO (Food and

Agriculture Organization) in 2010 by Perum Perhutani, as one of the state-owned forestry companies in Indonesia, and this is the area of teak plantations in Java (Java Island, Indonesia) only. Therefore, it is possible that the actual total area is greater, i.e., local farmers and small-scale holders of teak plantations are not included in that data [8].

The results of the data from FAO on global teak resources and the market assessment in 60 tropical countries show that the natural teak forests are in decline worldwide and that the quality of naturally grown teak is deteriorating. On the other hand, the survey reveals that the number of teak plantations is increasing. Teak has attracted large investments from the private sector in many countries for planting teak; thus, the area of teak plantations are increasing, and if well-management practices are applied, eventually these areas can be expected to produce high quality teaks [9].

The limitation of deforestation due to the environmental issues will particularly affect to the supply of teak from the natural teak forests especially. This will result in further limits on the production of teak from the natural forests and will also result in a shift of the supply of teak to the market from the natural forests to the teak plantations. In this case, India, Indonesia, and Myanmar, as countries with the largest teak plantations in the world, will likely maintain their market position [9].

In Indonesia especially, teak and its plantations are getting more priority than the other wood species. The importance of the teak plantations in Java Island, Indonesia, in addition of being wood production resources, the teak plantations also have another purpose for protection of soils on hills to minimize soil erosion into paddy fields in the lowlands. This

soil protection system has clearly demonstrated the values of teak plantations for soil conservation in those areas [10].

At the present, only in Java Island, there are at least 1.21 million hectares of teak plantations, as the second largest area of teak plantation in a country in the world. The average production of logs and timbers from these teak plantations are 0.4 million m³ annually [8, 11].

Teak plantations in Java have been operating by Perum Perhutani since it was officially founded in 1961. However, these teak plantations have been managed institutionally uses the modern operation by the colonial company since 1897, the time before Indonesia was founded as a country in 1945 [12].



Figure 3.3. Area of teak plantations surrounds the lowland area of paddy field in West Java area, Indonesia.

There are several lacking and inaccurate information regarding to the condition and management of teak plantations in Java. However, these teak plantations have been well managed and are functioning properly. All of wood logs and timbers produced by Perum Perhutani have been certified by the international certification organization, i.e. Forest Stewardship Council (FSC), and this forestry company was the first company in the world to be awarded the "Certificate of Rain Forest Alliance for Sustainable Forest Management" by The Rainforest Alliance, it is the world's leading which has developed the world's first global forestry certification program [13, 14, 15].



Figure 3.4. Young teaks in one of the teak plantations in West Java area, Indonesia.

Although there are different data about the width of area of teak plantations in several countries and its plantation management because of the lacking information, i.e. to the thinning and the commercial potential of young teaks, which comprise mostly sapwood,

but however the young teaks are still exists in some teak-producing countries, and these are one of the potential wood material that can provide the demand of wood for various occasions.

3.3 The Thinning Process of Teak Plantations in Java Island

The period from planting until harvesting is called *the rotation age*. Teak plantations in Java Island, Indonesia, which is managed by Perum Perhutani, use the rotation age of 40 years and the rotation age of 80 years. During the rotation age, a number of young teak trees, which mostly comprise sapwoods, will be felled due to the *thinning* to stimulate the best growth of remaining teak trees in the teak plantations. As a particular case, in one of the teak plantations, for 1 hectare of teak plantation with the site quality index of *bonita III/IV* (average quality class) and rotation age of 40 years, from 1,769 5-year-old teak trees will be felled regularly during the rotation age until 277 39-year-old teak trees remain at harvesting. There are six site classes, bonita I until bonita VI, which are the most fertile soil is classified as bonita I and the most infertile soil is classified as bonita VI. This soil classification is used for recognizing areas of teak plantation in Java Island, and each site class has the different thinning for felling the number of its teak trees [16].

Thinning is one method to stimulate the well growth condition according to the intended wood in the area of tree plantations. This method is based on the principle that the growth condition of a tree will be influenced by the surrounding physical conditions. The fertility and the height position of the soil and height of soil position will influence to the moisture level, water supply, and the amount of sunlight a tree receives. The nature has shown that the tree's position in the mountain or hillside will result in different characteristics of its

wood. In the *midpoint* with usually the distance among the trees are quite far, the trees will receive the best sunlight and air circulation, without excessive competition from neighboring trees. These trees are able to branch quickly and develop necessary girth to support a large amount of leaves. The trees in the lower position (below midpoint) have to compete for sunlight, and consequently will focus to be higher and straighter, with less branching [17].

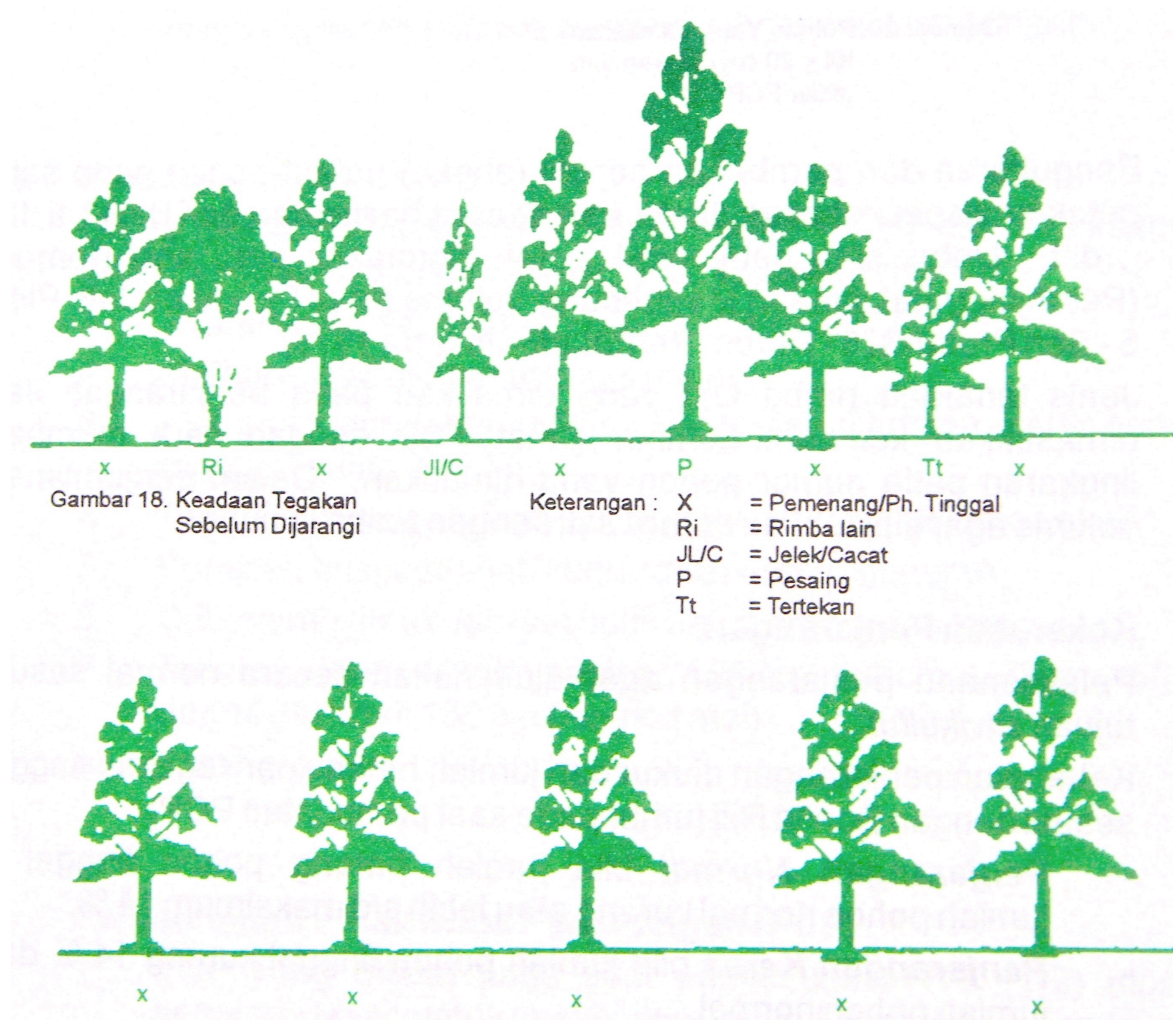


Figure 3.5. An illustration of teak site, before (above) and after (below) thinning process [18].

Perum Perhutani has been implementing the thinning on its own teak plantations since early, and currently some of non-profit organizations have been introducing also the thinning to the local farmers and private small-scale holders of teak plantations. This effort helps to increase the economic and social aspects from the appearance of their teak plantations in their area [19]. From the previous description, it is obvious that the thinning for the teak plantation does not have a bad impact to the environmental, and on the contrary that the thinning gives the benefits both to the surrounding of site areas and the communities.

3.4 Young Teak from the Thinning

Thirty-year-old teak trees (Class Age III) still have 51.27% sapwood and 40-year-old teak trees (Class Age IV) still have 36.67% of sapwood. Therefore, the young teak trees from the thinning must have at least 50% sapwood [20]. A relatively long time is needed for percentage of heartwood to become greater than its sapwood, and then appropriate to be felled and utilized, at least at age 40-year-old, and the ideal is at age 80-year-old. In this case especially, the growth period of teaks become a limited supply to meet the increasing demand of wood globally, and therefore, nowadays Perum Perhutani has been developing the new variety for rapid growing of teak tree which having shorter of 40 years rotation age.

Young teaks from thinning are available and have been used for firewood and also for making products, such as furniture, although with some limitation and relatively weaknesses due to their lower durability, smaller trunk size, bigger shrinkage, bigger distortion, and also the pale of its color.



Figure 3.6. Various age class of young teaks from the thinning of the teak plantation.

Table 3.2. Comparison between heartwood and sapwood percentage of teaks from a teak plantation area in Java Island, Indonesia [20].

Age Class	Range of Age	Heartwood (%)	Sapwood (%)
I	1-10-year-old	9.09	90.91
II	11-20-year-old	33.53	66.47
III	21-30-year-old	48.73	51.27
IV	31-40-year-old	63.33	36.67
V	41-50-year-old	73.14	26.86
VI	51-60-year-old	79.36	20.64
VII	61-70-year-old	79.69	20.31
VIII	71-80-year-old	89.93	10.07

At the Figure 3.7 and Figure 3.8, shown that the young teak now has been using for making furniture, which comprise sapwood and its heartwood has been used for this occasion without any extraneous treatment to its sapwood part, and these sapwood parts usually will be more decay easily than the heartwood parts after the certain time if the environmental condition that makes fungi and destroyer insects attack. However, by using of appropriate treatments, such as oven-dry seasoning and preservation with pressure, can improve the durability of sapwood to match that of heartwood. Other treatments, such as heating and removing starch and sap use the certain solvent, it can also make the sapwood possibly more durable and usable than before [21, 22].



Figure 3.7. Teak furniture in which is still comprise sapwood and its heartwood parts.

Now in the market and production of wooden teak products, there are not only mature teaks that usually could be bought and to be used, but also available young teaks for this occasion, as an effect of wood increased in demand but on the other hand it become limited in supply.



Figure 3.8. Sapwood of teak can be recognized as brighter color than the heartwood parts.

If consider to the possible amount of young teak from the thinning as one of the wood material resources, and on the other hand the increase of the world population has also increased to the global wood consumption, especially for high-grade tropical hardwoods, and the demand for wood is increasing from time to time, and therefore the substitute material should be found to meet this demand [7].

Application of teak (mature teak) as one of the prominent material for making the special and luxury products is has been being used from hundreds years ago until now, but on the other hand, the use of young teak for making products is just to be considered about

several years ago, due to the market demand of wood material is increasing, while the mature teak is becoming higher in market price and the supply of teak from the natural forest has decreased during the time. The other aspect also has occurred that the area of teak plantation is increased and therefore the supply of teak is dominated from the teak plantation in which the young teak is included due to the thinning process of its teak plantations [9].

In this case, the young teaks from the thinning are having possibility to contribute. It is necessary to utilize these potential material become suitable products by taking the advantage of its mechanical properties and prominent characteristics to enhance its utilization and value. This is important for Indonesia especially, who has the wide teak plantation area that is possible to be increased for getting the advantages from this potential material optimally.

Although the young teaks and teaks from the thinning are have been utilizing for making various products, but the assessment to its mechanical properties and characteristics are relatively limited. The data and information about teak usually refers to its mature teak, and it will be different to the young teak. Therefore, the assessment to the young teak from the thinning should be done for getting the specific properties and its characteristics. It is necessary to utilize these potential young teaks become suitable products by taking the advantage of its mechanical properties and prominent characteristics to enhance their utilization and value, both at present and in the future.

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CHAPTER IV

PROPERTIES AND CHARACTERISTICS OF YOUNG TEAK

4.1 Assessment Method for Young Teak

For the assessment of properties and characteristics of young teak in this research, five teak trees sample are taken from West Bandung County, West Java area, Indonesia. These teak trees are consists of one of age class I, two of age class II, one of age class III, and one of age class IV. The geographic coordinates of this teak trees area is between 60° 41' - 70° 19 South and 107° 22 - 108° 05' West, whereas the altitude from the sea level above is various from 500 - 1000 m., and the average annual rainfall in this field area is about 2500 - 3000 mm/year [1].

Teak materials for making of specimens of tests in this research are categorized as:

1. The young teak logs from the thinning of teak plantation, which is still comprise mostly sapwood part; and
2. Small beams or planks of sawing and re-sawing of teak logs, timbers, or lumbers, which is still contain proportions of both sapwood and its heartwood part. These are recognized as removed waste material, not standard size and narrow relatively.

For the tests occasion, teak material has been categorized in range as Age Class I (1-10 year-old), Age Class II (11-20 year-old), Age Class III (21-30 year-old) and Age Class IV (31-40 year-old).

Teak trees for research have been felled and sawn into planks, and then these materials have been dried to reduce of its moisture content by the drying process of seasoning until air-dry condition has been reached. For reducing the drying time, kiln drying is also used for getting the low moisture according to the standard for testing is feasible, i.e. maximum moisture content is 20%. The planks of teak are re-sawn and processed into various and specific specimens according to certain testing occasion respectively.

Determination in this assessment is conducted by the adaptation from the standard of ASTM (American Society for Testing and Materials) D143-09, 2009, Standards Test Methods for Small Clear Specimens of Timber [2]. The standard in this research is combined with the SNI (Standar Nasional Indonesia), SNI 03-3960-1995, Test Method for Modulus of Bending Elasticity of Wood in Laboratory [3]. Consideration of using this combination standard is intended to the condition of the place where the teaks are processed to be cut and to be made become various structural size of planks, beams, logs, and products for both domestics and exports market occasionally, and also due to the limitation of the size of sapwood part of the teak especially.

Teak planks and teak specimens are prepared for determination of its following mechanical properties, which are including weight density, maximum load, modulus of rupture (MOR), and modulus of elasticity (MOE) respectively. These mechanical properties can indicate the strength of its wood. Machine strength grading is used for strength determining in this research. At the same time, those teak planks are used for recognizing of its characteristics, i.e. grain pattern and color of surface on its transverse, tangential and radial section.

Strength is defined as the ability to resist an applied stress. The resistance is measured in two methods, the first is the maximum stress that the material can endure before failure occurs, and the second method is to measure the strain or deformation that results from a given level of stress before the point of the total pressure makes failure or crash (rupture). Stress is the amount of force that is given at a unit of area, and the strain is defined as unit deformation or movement per unit from its original length. MOR is the maximum load carrying capacity of a member, and MOE is the ratio of stress to strain. Within the elastic range below the proportional limit, this ratio is a constant for a given piece of wood.

The test in this assessment is conducted for the specimens from various age classes of teak, both sapwood and its heartwood part for occasionally comparison. The sapwood and its heartwood part of young teaks from age class I, age class II, and age class III, as age classes in the rotation age of 40 years of teaks plantation, are separated each other for determination of its MOR and MOE. Teak planks from both sapwood part and its heartwood part are cut and sawn to be specific size and form, according to its testing occasion respectively.

The data was obtained from the testing machine, i.e. universal testing machine (UTM), to determine of its maximum load until rupture completely for each specimen. The data that appear from the table and its graphics will be used to calculate for getting both MOR and MOE of the specimens respectively. The result data is the average calculation from each specimen in the same classes and categories to determine the grade of its MOR and MOE according to the referenced standard.



Figure 4.1. The monitor display in UTM shows the increasing loads of pressure to the specimen during the test.

Type of test is static bending with the three-points. It is the center point loading and two supporting bearing, and which the pressure of loading is perpendicular to the grain of the specimens. This test is for determination of the strength. It is generally used in test of bending strength to quantify the stress required to cause failure. Speed of test (displacement control) of the UTM is set at 0.1 inch/min (2.54 mm/min), as the type of control by position (mm/min), and the load control is set for 10 kgf/s (98.0665 N/s).

Before the test of assessment is started, the specimens shall be checked to its weight density and the moisture content, and also the temperature and the humidity of the place where the test will be conducted, and shall be according to the certain standard that will be adapted, i.e. it is combination of standard in ASTM and also in SNI.



Figure 4.2 The teak specimen was testing of the static bending by the Universal Testing Machine (UTM).



Figure 4.3. Tools for checking the weight and the moisture content of the specimen, the humidity and the temperature of testing area.

Consider to the physical and natural condition of the testing place, and also to the standard that is used for determination, this test is conducted at 60% ($\pm$ 5%) of relative humidity, 25⁰C - 27⁰C of temperature, and 20% of maximum for moisture content, with 15% - 19% at radial surface and 16% - 19% at tangential surface. Number of specimen for *static bending test*, at least 5 pieces for each age classes, both sapwood and its heartwood part [2, 3]. Detail information about the test as it is presented in Table 4.1. For additional tests, number of specimen is 2-3 pieces for each age classes and each type of specimen respectively that is conducted for six various tests including bonding test to determine ease of bonding categories of young teak in particular.

Each specimen are tested by the UTM until the maximum load is reached, it is mean that the specimen will be pressed, i.e. static bending, until the specimen is rupture. For every load of the pressure to the specimen per unit time, i.e. millisecond and less, will be presented in the table data as it is described in Table 4.2. This table is just shows the examples data of one of the specimens, and it is only pointed to several positions as an illustration example.

Beside the data in Table 4.2, the result of test also will be described in four different graphics data that can describe the correlation condition among load/force, time, position, stress and strain of a specimen that occurs during the test, since the start of pressure until rupture, as it is presented in Figure 4.4. In spite of that data in Figure 4.4, the precise data for determination of MOR and its MOE only can be obtained from the certain point of its reference data as it is presented in Table 4.2.

Table 4.1. Sample data information for static bending test of small clear specimens.

Standard Methods of Testing	Adapted from ASTM, Designation: D 143-09 (2010) (<i>Small Clear Specimens of Timber</i>), and SNI 03-3960-1995, <i>Test Method for Modulus of Bending Elasticity of Wood in Laboratory</i>
Time of Test	Session I: March 2013 Session II: September 2013
Laboratory	Structure Engineering Laboratory - Bandung Institute of Technology, Indonesia.
Machine/Device	UTM (Universal Testing Machine) Ibertest, series Eurotest - 200, Made in Spain; Year of production: 2012.
Speed of Testing (displacement control)	0.1 inch/min (2.54 mm/min); <i>Type of Control by Position (mm/min)</i> ; load control 10 kgf/s (98.0665 N/s)
Humidity	60% ($\pm 5\%$)
Temperature	25 ⁰ C - 27 ⁰ C
Size of Specimen	20 x 20 x 300 mm ³ (width x depth x length)
Number of Specimens	6 pieces of sapwood part specimens for each ages class (I, II, and III); and 12 pieces of heartwood part specimens for each age class (I, II, III, and IV); Total number is 66 pieces of specimens
Moisture Content of Specimens	at the radial surface: 15% - 19%; and at the tangential surface: 16% - 19%; (<i>standard maximum is 20%</i>)

Table 4.2. Example of reference data of test uses UTM for each specimen respectively.

Field	Value	Unit
Date of test	16/09/2013 11:54	
Test maximum load	1.319	kN
Test maximum strength	3.298	MPa
Maximum position	12.575	mm
Reference	T 1 (I1H1)	
Time (s)	Load (kN)	Position (mm)
268.036	1.3175	11.34594
268.056	1.31475	11.34678
268.078	1.2585	11.34761
268.1	-0.0355	11.34844
268.122	-0.01775	11.34929
268.144	-0.01625	11.35024

The process of obtaining data for measuring of MOE is taken from the relation between load (force) and its position that is presented as the graphic of data as it is illustrated in Figure 4.5. Each point throughout this graphic line is representation of the load per unit time, from the start loading until the specimen failure or rupture (maximum load). From the graph, it should be made a strike line, start from the base of graph until the certain point along the curve that the load starts to be decreased gradually. The end of the strike line, which is coincide in this curve, is the point of proportional limit that will be taken for the determination of MOE.

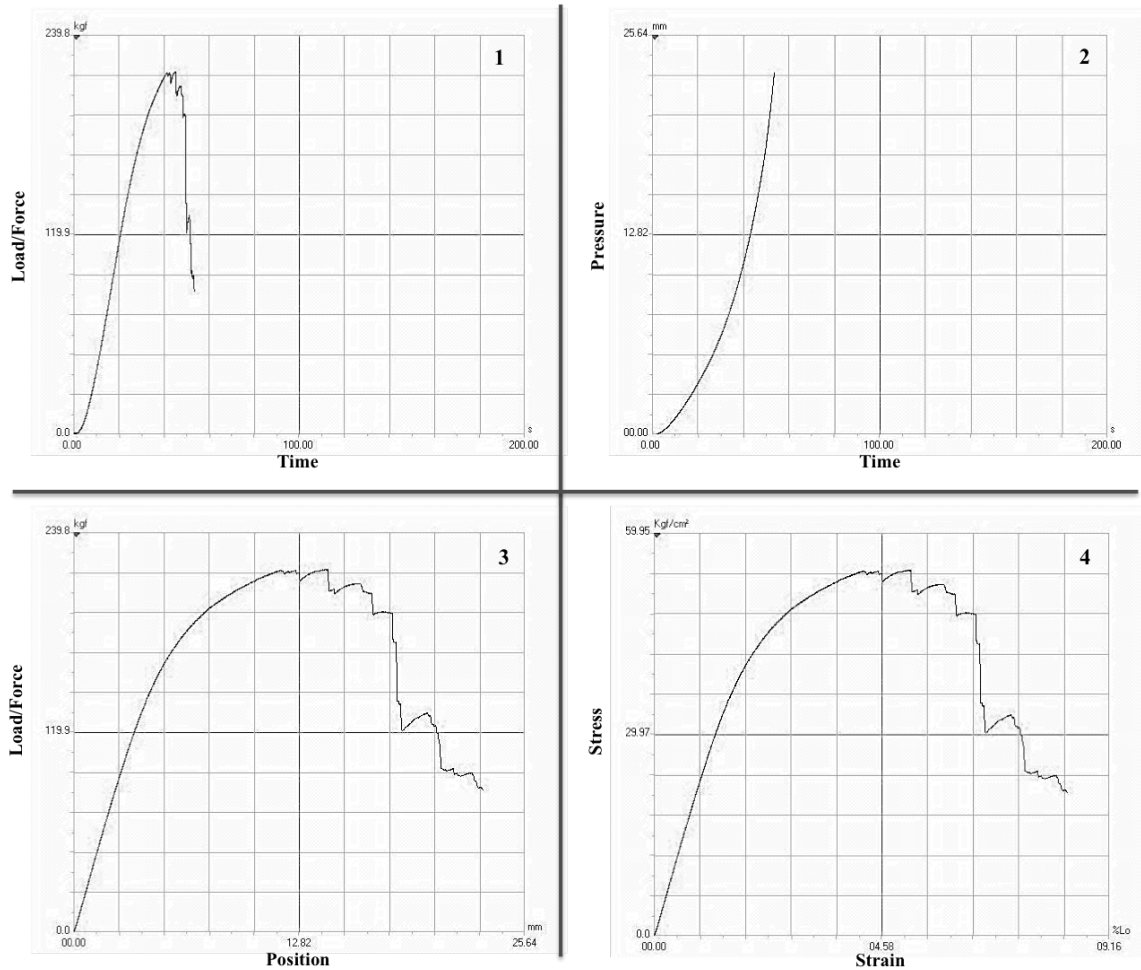


Figure 4.4. A set of graphics data for which describe the test of a specimen respectively.

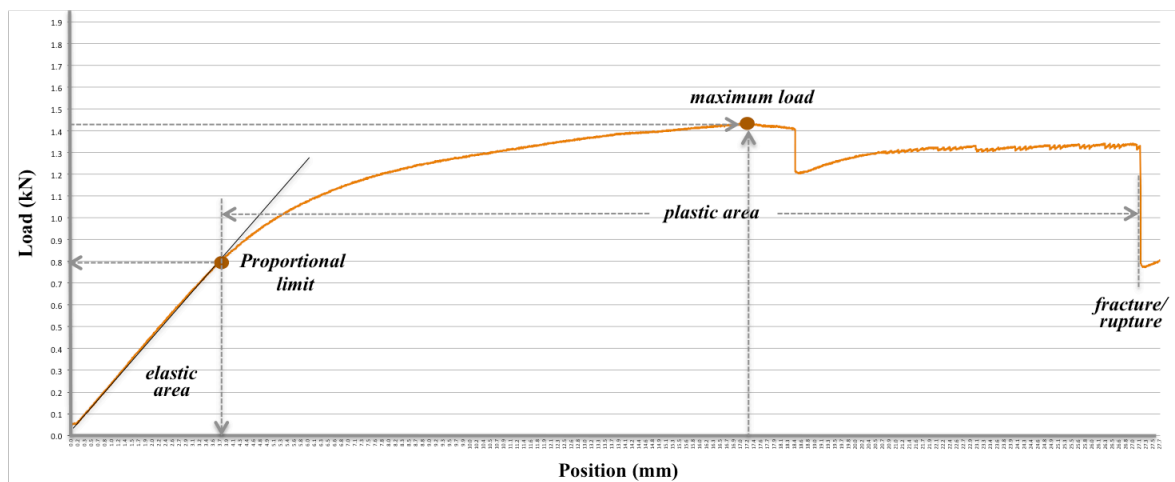


Figure 4.5. Diagram of deformation and load point position for determination of MOE.

Equation which is used for determination of MOR and MOE of small clear specimens in this assessment are defined as:

$$\text{Stress} = \frac{F}{bd}$$

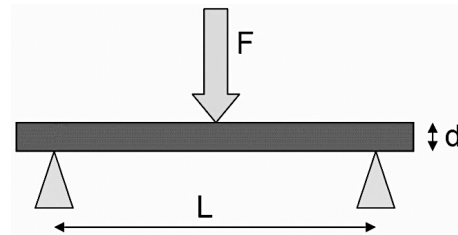
where $F = \text{Load or Force (N)}$

$bd = \text{Area (m}^2\text{)}$

$\text{Stress} = \text{Pressure (N/m}^2\text{) or (Pa)}$

Use of classical beam equation and section properties, for rectangular sample of specimen under a load in a three-point bending setup, the resulting stress under an axial force is given by the following equation:

$$\text{Bending Stress} = \frac{3FL}{2bd^2}$$



Bending stress is equal with the Modulus of Rupture (MOR) and its Modulus of Elasticity (MOE), and these are defined as:

$$\text{MOR} = \frac{3FL}{2bd^2}$$

where $F = \text{Load or Force (N)}$

$L = \text{Length of support span (m)}$

$b = \text{width (m)}$

$d = \text{depth or thickness (m)}$

$y = \text{deflection at load point (m)}$

$$\text{MOE} = \frac{FL^3}{4bd^3y}$$

4.2 Categories of Mechanical Properties Data

According to the document of ASTM assessment, the everyday use of wood for various occasions, make the data of mechanical properties of the wood need to be updated due to the great variety of species, the variability of the material, the continually changing conditions of supply, the many factors affecting test results, and all combines to make the technique of wood testing is unique in its complexity.

The test methods cover the determination of various strength and related properties of wood by testing of small clear specimens. These test represent the entire procedure from selection of the trees to the carrying out of the tests of specimens, thus controlling factors such as its size and proportion, and rate of loading that may influence to the results.

These test methods cover the tests on small clear specimens of wood that are made for these purposes, such as [2]:

1. Giving the data for comparing the mechanical properties from various species;
2. Comparing data for establishment of correct strength function which, in conjunction with results of tests of timbers in structural size, and;
3. Considering data upon which to determine the influence on the mechanical properties of such factors as density, locality of growth, position in cross section, height of timber in the tree, change of properties with seasoning, and the change from sapwood to heartwood.

According to air-dry material character, the raw material (teak trunks) and the specimens have been stored in a place that allowing free access of air, but protected from sunshine,

rain, the moisture from the ground, and the specimens are not subjected to the artificial heat.

Consider to the characteristic of wood as a hygroscopic material, and therefore the specimen should be checked frequently and properly before the test is started to ensure the accurate results. The specimen has reached the acceptable condition, approximately 15% - 19% MC, and store in the normal room temperature ($20 \pm 3^{\circ}\text{C}$, $65 \pm 1\%$ relative humidity).

The assessment has been conducted for several type of obtaining and calculation result for small clear specimen testing. The tests are divided into 7 categories and 1 measuring. The weight measurement is completed for each category respectively. These categories of test are:

- A. Static Bending (*Perpendicular to grain*)
- B. Compression Strength Parallel to grain
- C. Compression Strength Perpendicular to grain
- D. Tension Strength Parallel to grain
- E. Tension Strength Perpendicular to grain
- F. Cleavage Strength Parallel to grain
- G. Shearing Strength Parallel to grain; and
- H. Measuring of Weight Density

In this research, for additional data, the assessment also has been conducted the number of tests for getting the mechanical and bonding properties of young teak. Bonding practice

has been conducted and it has been compared the strength of bonding among teak, young teak and another wood material for comparison occasion.

According to some research, teak has been recognized as the wood with bonding difficulty, as is described in Table 4.3. This recognition may refer to the bonding property for mature teak, and therefore it is possible that the young teak is having the different property. The determination to examine of bonding characteristic is necessary to be conducted for comparing the ease bonding categories. This test is important if consider the application of these material, i.e., young teaks, for making various products which usually need bonding for connection, joint system, etc.

Table 4.3. Several Selected Wood Species According to Ease of Bonding Categories [B]

Category	Example of wood species
Bond Easily: Bond very easily with adhesives of a wide range of properties and under a wide range of bonding conditions.	Pine (Eastern White, Western White), Spruce, Redcedar (Western), Redwood, Balsa
Bond Well: Bond well with a fairly wide range of adhesives under a moderately wide range of bonding conditions.	Pine (Sugar, Penderosa), Maple (Soft), Walnut (Black), Meranti (Light Red, White, Yellow), Mahogany (African, American)
Bond Satisfactorily: Bond satisfactorily with good-quality adhesives under well-controlled bonding conditions.	Pine (Southern), Maple (Hard), Oak (Red, White), Meranti (Dark Red)
Bond with Difficulty: Satisfactory results require careful selection of adhesives and very close control of bonding conditions; may require special surface treatment.	Persimmon, Keruing, Rosewood, Balau, Kapur, Teak

4.3 Mechanical Properties of Young Teak

For the mechanical properties of young teaks, some research has concluded that there is no significant difference in the strength between heartwood and its sapwood. This is likely because there are no differences in their structures and there is no changing anatomically. The difference in strength is closely correlated to the density of its wood. The difference recognized only to the content of materials in their cells, which is related to the durability of its wood [4, 5]. Under the most condition, i.e. suitable moisture and temperature, with adequate oxygen and food, the sapwood will decay more easily than its heartwood after a certain period of time [6].

This research also has determined that the difference strength between sapwood part and its heartwood part is not significant. However, some interest and distinctive data appears to be considered later. The testing results of this assessment of the young teaks that are compared to the mature teaks from this research are shown in Table 4.6. The total number of specimens is 66 pieces. The number of sapwood specimens for each age class is 6 pieces (age class I, II, and III), and the number of heartwood for each age class is 12 pieces (age class I, II, III, and IV). The number of sapwood part is half of heartwood part, which is caused by the limited of certain size and volume of sapwood part than the heartwood part, especially for making the specific size of specimen. The standard properties of mature teak are accompanied for comparable data.

According to the strength classification of the wood in Indonesia, as it is described in Table 4.4, the strength class is divided into five classes, which is the strength class I for highest, and the strength class V for the lowest. These strength classes are usually referred

according to the weight density of the wood and its MOR. Teak from Java Island has been recognized as the wood with the standard strength class II [7, 8]. For comparison to another researcher, in Table 4.5, the teaks from various age-class have been recognized. These teaks are from the eastern area of Java Island, which is usually recognized as the area of teak plantation with the Bonita 1-III (low fertility relatively).

Table 4.4. The standard of Strength Class for Wood in Indonesia [8].

Strength Class	Weight Density	MOR (MPa)
I	> 0.90	> 107.87
II	0.60 - 0.90	71.098 - 107.87
III	0.40 - 0.60	49.03 - 71.098
IV	0.30 - 0.40	35.30 - 49.03
V	< 0.30	< 35.30

Table 4.5. Mechanical properties of teak on various age classes from other determination as comparison data [9].

Age Class of teak (year-old)	Weight Density (gr/cm³)	MOR (MPa)	MOE (GPa)	Classified as Strength Class
I (1-10)	0.51	70.00	3.93	III
II (11-20)	0.61	108.46	6.74	II
III (21-30)	0.59	121.80	8.63	II/III
IV (31-40)	0.61	109.64	7.68	II

The assessment results of the test for *static bending* with *perpendicular to grain* are described in Table 4.6.

Table 4.6 Mechanical properties of sapwood and heartwood of teak from various age classes.

Age Class of teak (year-old)	Part in wood trunk	Weight Density (gr/cm ³)	Maximum Load (kN)	MOR (MPa)	MOE (GPa)	Strength Class	
						Based on Weight Density	Based on MOR
I (1-10)	SW	0.613	1.004	52.709	6.989	II	III
	HW	0.635	1.529	80.263	7.051	II	II
II (11-20)	SW	0.652	1.741	91.413	10.029	II	II
	HW	0.617	1.650	86.657	8.893	II	II
III (21-30)	SW	0.622	1.744	91.570	9.332	II	II
	HW	0.720	1.745	91.615	9.438	II	II
IV (31-40)	SW	<i>Size of SW part is smaller than the standard size for testing occasion</i>				-	-
	HW	0.781	1.555	81.623	8.840	II	II
Teak (standard)		0.67 - 0.75	-	101.106	12.523		

From the Tables 4.4 and Table 4.6, those are shown that the strength class based on weight density among the age classes is in the same range for strength class II, and also the strength class based on MOR among the age classes is in the same range for strength class II. The exception is only for sapwood of age class I. This sapwood part is in the range of strength class III.

The mechanical properties are the determination of Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE) of these young teaks. According to the test result, the difference strength between heartwood part and its sapwood part of young teak among the age class II, and the age class III are not significant, and also if these are compared to the age class IV which is recognized as the mature teak.

The comparison between MOR and MOE from this determination is as described in Figure 4.6. Although the result of MOE is lower than the standard of MOE for teak (mature teak) and wood in general, but the result is in the same tendency to its MOR relatively. It is meant that there is a consistency between the result of MOR and its MOE. The standard average of MOE for wood is 11 - 16 GPa, whereas the standard average of MOE for teak is 12.523 GPa, and MOR is 101.106 MPa [7, 8].

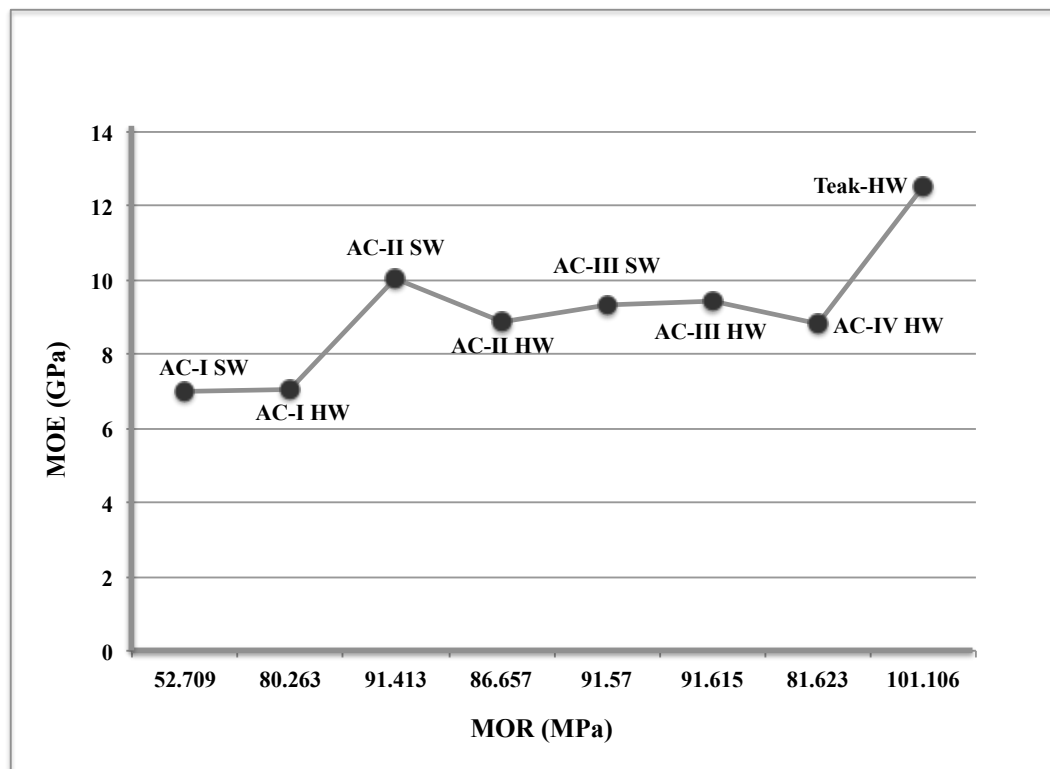


Figure 4.6. Comparison between MOR and its MOE.

In this research, for additional data, the assessment also has been conducted the number of tests for getting the mechanical properties of young teak. The data from the additional test will be important for the application of young teak for making various products. For the tests occasion, teak material has been categorized in range as Age Class I-II (10-20 year-old) and Age Class III-IV (30-40 year-old).

Standard methods for testing are adapted and modified from the ASTM, Designation: D 143 (Small Clear Specimens of Timber) [12], and then it is combined to SNI 03-3960-1995, Test Method for Modulus of Bending Elasticity of Wood in Laboratory [13]. The laboratory for testing is conducted at Structure Engineering Laboratory - Bandung Institute of Technology, Indonesia. The device/machine for testing is Universal Testing Machine (UTM) Ibertest, series Eurotest - 200, Made in Spain; Year of production is 2012. The speed of testing (displacement control) of UTM is set to the type of control by position, and the speed is set according to the standard for each test categories respectively, but the load control for all of the test are set at 98.0665 N/s (load increasing). Time of tests has been arranged in March and September 2013.

For getting the appropriate result, before the test is started, all of the specimens must be confirmed of its moisture, it is not exceed more than 20% (standard of maximum), and also the humidity and temperature of the place where the test is conducted. The tests have been conducted in relative humidity 60% ($\pm 5\%$) and temperature 25°C-27°C, and the moisture content of the specimen is 15%-19% at radial and 16%-19% at tangential. Number of specimen is 2-3 pieces for each age classes and each type of specimen respectively that is conducted for six various tests.

The categories of test in this research are the command tests those are usually conducted to determine the mechanical properties of wood as material. The test consists of:

1. Compression Strength Parallel to grain;
2. Tension Strength Parallel to grain;
3. Compression Strength Perpendicular to grain;
4. Tension Strength Perpendicular to grain;
5. Cleavage Strength Parallel to grain; and
6. Shearing Strength Parallel to grain.

The basic data has been added also by the Measuring of Weight Density, as one of determination factor for confirmation of strength class, and in this case, the weight density as a sample to compare among the specimen from the various age class and wood species.

This research has been conducted of tests for getting the bonding properties of young teak in particular. Falcata (*Paraserianthes falcataria*) and Kapur (*Dryobalanops beccari*), are used for comparison in bonding test. These wood are represented as bond easily and bond with difficulty, according to ease of bonding categories as shown in Table 4.3. Type of adhesive that is used in these tests is poly vinyl acetate (PVAc), as ordinary glue for bonding of wood in general occasion.

Identical with the previous test, standard methods for these tests are also adapted and modified from the ASTM, Designation: D 143 (*Small Clear Specimens of Timber*), and then it is combined to SNI 03-3960-1995, *Test Method for Modulus of Bending Elasticity of Wood in Laboratory*. The laboratory for testing is conducted at Structure Engineering

Laboratory - Bandung Institute of Technology, Indonesia. The device/machine for testing is Universal Testing Machine (UTM) Ibertest, series Eurotest - 200, Made in Spain; Year of production is 2012. For getting the appropriate result, before the test is started, all of the specimens must be confirmed of its moisture, it is not exceed more than 20% (standard of maximum), and also the humidity and temperature of the place where the test is conducted. The basic data also has been added by the *Measuring of Weight Density*, as one of determination factor for confirmation of *strength class*, and in this case, the weight density as a sample to compare among the specimen from the various age class.

The test results for each type of testing that is especially applied to the young teak specimens and another wood material are described in several Test Data Sheets respectively. The tests are conducted for each type of specimen with and without adhesive applying. Bonding test is as an adaptation in which is based on its basic tests as is illustrated in Figure 4.7 and Figure 4.8, whereas the tests results as are described in Table 4.7 - Table 4.11.

Table 4.7. Test data sheet of compression strength parallel to grain

Speed of Testing		0.024 inch/min (0.6 mm/min)		
Size of Specimen		20 x 20 x 80 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Wood Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.63	33.539	33.539
	HW	0.63	17.726	17.726
III-IV (30-40)	SW	-	-	-
	HW	0.69	45.284	45.284
Teak (<i>standard</i>)		0.67	-	53.937



Figure 4.7. Compression (A) and tension (B) parallel to grain, and compression perpendicular to grain (C) tests assembly

Table 4.8. Test data sheet of tension strength parallel to grain

Speed of Testing		0.05 inch/min (1 mm/min)		
Size of Specimen		20 x 20 x 300 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Wood Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.63	9.696	96.963
	HW	0.64	8.213	82.135
III-IV (30-40)	SW	-	-	-
	HW	0.69	9.631	96.311
<i>Adhesive applied</i>				
I-II (10-20)	SW	0.62	1.583	3.957
	HW	0.69	1.654	4.135
III-IV (30-40)	SW	-	-	-
	HW	0.69	0.966	2.390
Falcata		0.33	1.268	3.173

Table 4.9. Test data sheet of compression strength perpendicular to grain

Speed of Testing		0.012 inch/min (0.305 mm/min)		
Size of Specimen		20 x 20 x 60 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.63	5.516	13.788
	HW	0.64	7.9525	19.878
III-IV (30-40)	SW	-	-	-
	HW	0.69	9.668	24.173

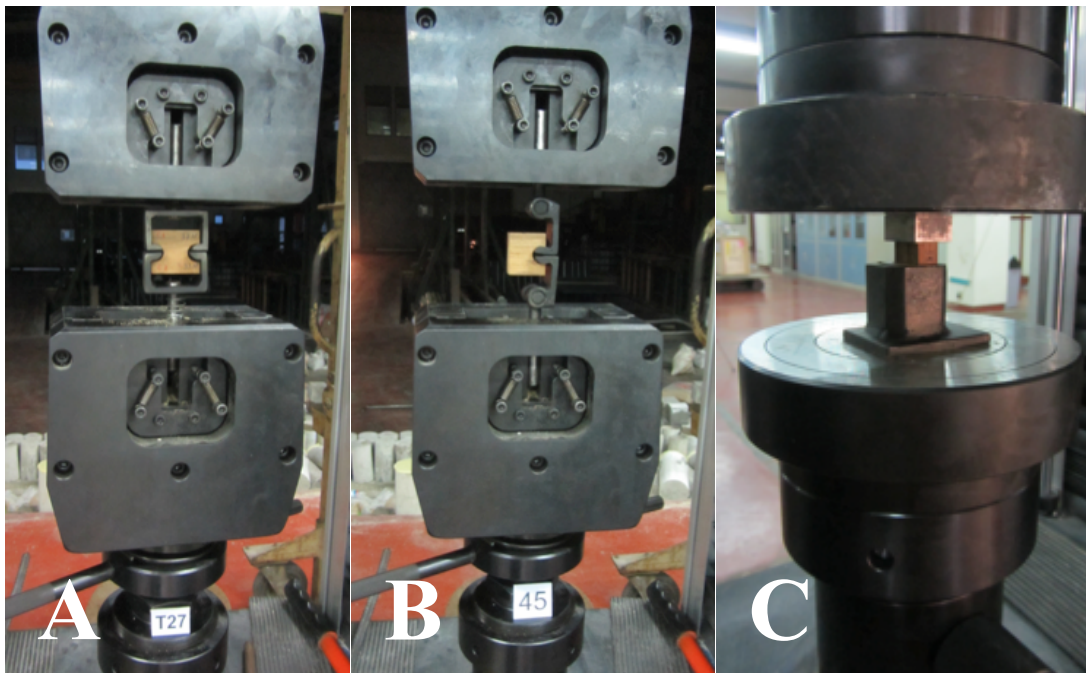


Figure 4.8. Tension perpendicular to grain (A), cleavage (B), and shearing (C) tests assembly

Table 4.10. Test data sheet of tension strength perpendicular to grain

Speed of Testing		0.10 inch/min (2.5 mm/min)		
Size of Specimen		35 x 20 x 40 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.63	2.328	5.820
	HW	0.63	2.812	7.031
III-IV (30-40)	SW	-	-	-
	HW	0.69	1.872	4.680
Falcata		0.33	0.901	2.254
Kapur		0.59	2.297	5.744
<i>Adhesive applied</i>				
I-II (10-20)	SW	0.63	1.732	4.331
	HW	0.64	1.773	4.433
III-IV (30-40)	SW	-	-	-
	HW	0.69	1.781	4.453
Falcata		0.33	0.640	1.601
Kapur		0.59	0.994	2.486

Table 4.11. Test data sheet of cleavage strength parallel to grain

Speed of Testing		0.10 inch/min (2.5 mm/min)		
Size of Specimen		35 x 20 x 30 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.62	0.730	1.824
	HW	0.69	0.874	2.184
III-IV (30-40)	SW	-	-	-
	HW	0.69	0.902	2.256
<i>Adhesive applied</i>				
I-II (10-20)	SW	0.62	0.600	1.500
	HW	0.69	0.400	1.000
III-V (30-40)	SW	-	-	-
	HW	0.69	0.354	0.885

Table 4.12. test data sheet of shearing strength parallel to grain

Speed of Testing		0.24 inch/min (0.6 mm/min)		
Size of Specimen		20 x 20 x 30 mm ³ (<i>width x depth x length</i>)		
Age Class (year-old)	Part in Trunk	Weight Density (gr/cm ³)	Max. Load (kN)	Max. Load to Area (MPa)
I-II (10-20)	SW	0.62	5.611	14.028
	HW	0.69	6.820	17.049
III-IV (30-40)	SW	-	-	-
	HW	0.69	5.418	13.545
<i>Adhesive applied</i>				
I-II (10-20)	SW	0.62	3.828	9.568
	HW	0.69	5.265	13.162
III-IV (30-40)	SW	-	-	-
	HW	0.69	1.319	3.297

For the mechanical properties those are based on its weight density and MOR, this research has been determined that there is no significant difference of strength between sapwood and its heartwood part of young teak among the age classes. The determination result is in the same range of the strength class II. The exception is for the sapwood part of the age class I, which is in the range of the strength class III.

In comparison with the grade of strength in the range of MOR and MOE those are compared to the standard of mature teak, all of the determination results of sapwood and its heartwood part of young teaks in this research are in the lower position than the particularly standard of strength for mature teak.

The lower position of determination could be caused by the smaller size of specimens. Although this test uses the acceptable minimum standard size of the young teak specimen that could be graded by the UTM (machine grading), but it is possible effects to the determination of MOR and its MOE, i.e. the grade is lower than the standard strength of mature teak. Nevertheless, almost all of the determination result is still in the same range of strength class (strength class II).

Another aspect that can effect to the determination is moisture content of the specimen. The mechanical properties of teak that conducted for testing in different condition, i.e. especially the moisture contents, would be possible have the different determination for both MOR and MOE. Therefore, all of the data should be completed by the specific information of the moisture contents respectively, and the determination should be arranged properly in accordance with the requirements of the certain testing standard that is adopted in the test.

Although some literatures have been recognized that the teak is one of wood with bonding difficulty character, but it refers to the mature teak. In this assessment has shown that the young teak has performed as good for bonding or at least possibly for bonding. The result has shown that bonding is possible relatively to be applied for young teak especially, and this bonding characteristic is usable for wood jointing in particular for making products in which bonding is applied.

4.4 Characteristics of Young Teak

Based on visual observation to the transverse surface, radial surface, and its tangential surface of young teak, as shown at this Figure 4.9.

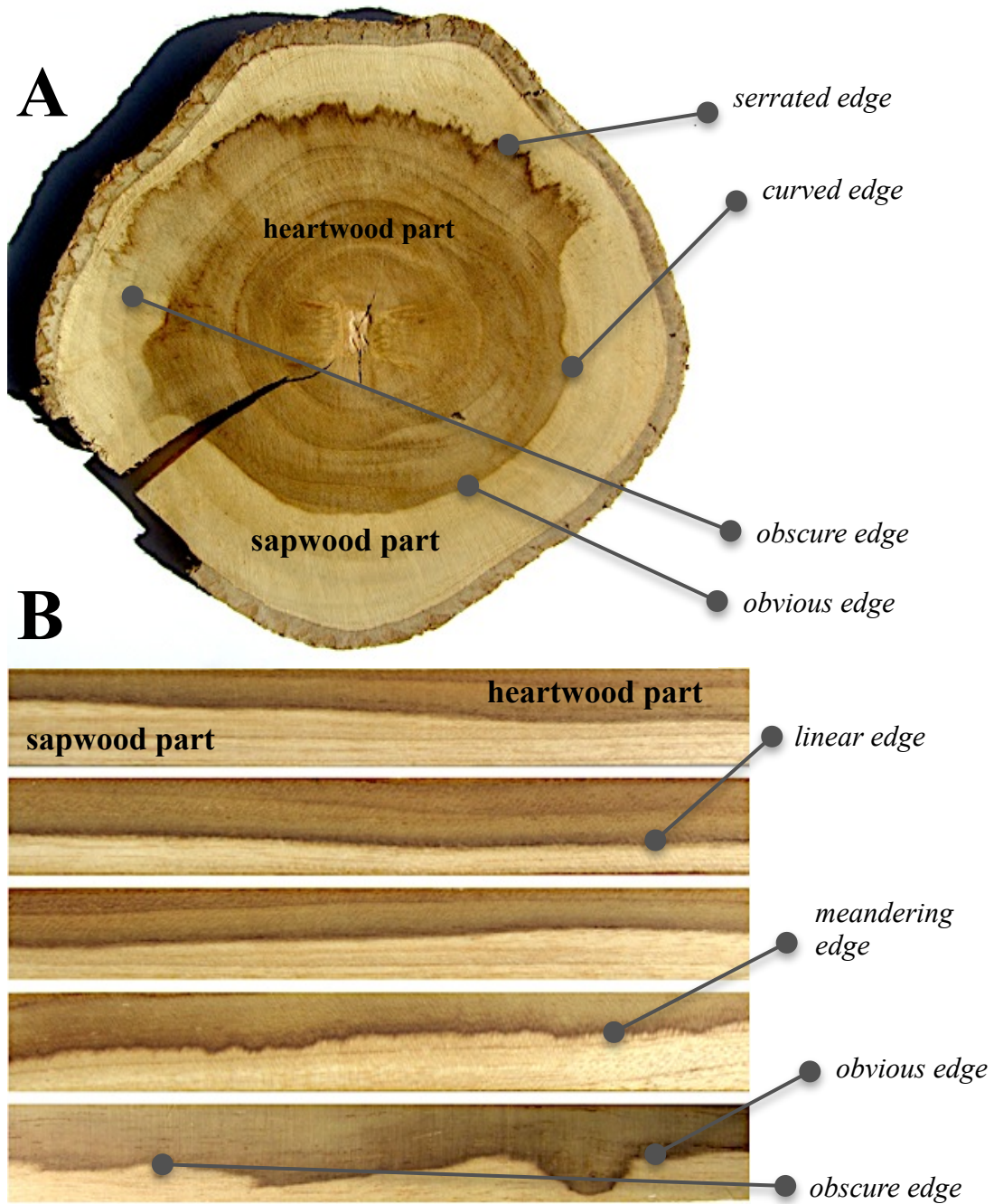


Figure 4.9. Category of border pattern at transverse surface (A), radial and tangential surface (B) of the young teak

For most of mature teaks, *border pattern* and color between sapwood and its heartwood are usually obvious. This is contrary to the young teaks in which the borders vary due to the incomplete process from sapwood to heartwood. Thus, these various border patterns are recognized in the *transverse surface* can be categorized as:

- A. *Serrated Edge* (saw-like), in contrast with *Curved Edge*;
- B. *Obvious Edge*, in contrast with *Obscure Edge*.

Whereas at both the *radial surface* and the *tangential surface*, the various borders are recognized as:

- A. *Linear Edge*, in contrast with *Meandering Edge*;
- B. *Obvious Edge*, in contrast with *Obscure Edge*.

The color intensity near to the borders edges on the heartwood parts also vary; darker and brighter color alternate between early-woods and late-woods at the growth rings, as an uneven process of formation and conversion of sapwood becomes heartwood. This darker color in the heartwood part is recognized because of the appearance of extractive composition in part of wood trunk due to the changing of sapwood (outer part) to heartwood (inner part).

For early assessment to the properties of young teaks in particularly, this experiment is conducted to determine the different of color lightness of sapwood and its heartwood of young teak after coloring. Based on visual observation to the color of sapwood and its heartwood, and the relation with, i.e. finishing system, as it is shown in Figure 4.10, that the different color intensity between coloring on heartwood surface and its sapwood

surface can cause the different intensity also after getting of colorant and polishing. In Figure 4.10, pieces A, D, and G are the heartwood of mature teak; pieces B, E, and H are the heartwood of young teak; and pieces C, F, and I are the sapwood of young teak.



Figure. 4.10. Comparison colorant intensity on sapwood and its heartwood surface.

The finishing system uses water-based polish as a non-toxic and eco friendly polishing, and the stain uses colorant for food grade. The type of this finishing system is clear finish and open pore, it is meant that the grain and pore of the wood surface are still obvious and recognizable.

This research conducts to determine the characteristic of color lightness of teak surface from the previous research. The data is determined uses lux meter at daylight shade in the midday condition ($\pm 20,000$ lux), and the distance between lux-meter to the specimens is 100 cm. The main purpose of this determination is conducted for getting the ratio comparison among various teak surfaces after coloring by colorant (food grade type) and water based polishing respectively.

For measuring the brightness of the surface after coloring, all of the surfaces are measured by the lux meter application in smartphone. Although the inaccurate result of brightness is possibly, but the important one is the ratio among the surfaces of teak, i.e. heartwood of mature teak, heartwood of young teak, and sapwood of young teak after coloring, have shown the different ratio.

Table 4.13. Lightness of Teak Surfaces

Teak Surface	without colorant (klx)	use colorant			
		Red (klx)	Green (klx)	Blue (klx)	Yellow (klx)
HW (mature)	5.7	4.1	4.2	5.4	5.3
HW (young)	8.1	4.6	5.4	6.2	6.4
SW (young)	10.4	5.3	7.2	7.0	8.9

Table 4.14. Ratio of lightness of young teak surfaces to mature teak surface

Teak Surface	without colorant	use colorant			
		Red	Green	Blue	Yellow
HW (mature)	1	1	1	1	1
HW (young)	1.42	1.12	1.28	1.14	1.20
SW (young)	1.82	1.29	1.71	1.29	1.67

The sapwood surfaces are having higher lightness than its heartwood surfaces. This can be determined that after the use of colorant, the sapwood part surfaces indicate the higher ratio in which is compared to the mature teak in the same each color of colorant respectively. There are significant different ratios of brightness among the various teak surfaces after coloring by the basic color of colorant as is described in Table 4.13 and Table 4.14.

For the characteristics of young teaks those are compared to its heartwood, one of the results has shown that the lighter color of sapwood surface has specific effect, i.e. to the finishing system. As a consequence of the difference in color intensity in sapwood and its heartwood part, wood stain that is applied to the sapwood surface, which is lighter color than its heartwood, will appear more attractive than in the heartwood surface, these effect especially will occurs if the wood stain which uses *fancy color*, as the popular name for kind of finishing. In this case, e.g. E and H pieces those are compared to F and I pieces in Figure 4.10.

The sapwood surfaces have the higher lightness than its heartwood surfaces. This is meant that the sapwood surface is lighter than its heartwood surface. Difference intensity of basic color has shown from the various part of teak after polishing by colorant and water base polish. In the same color using, the result has shown that the darker color surface appears from the pieces of heartwood part and the lighter color surface appears from the pieces of sapwood part. Caused by the lighter color of sapwood surface, the coloring on sapwood surface will appear more *attractive* and *vivid* than on its heartwood.

This research has recognized that the characteristic between sapwood and heartwood part differ in the border patterns of transverse, radial, and its tangential surfaces, and the color intensity differ in the effect of coloring on the surfaces of sapwood and heartwood part. The pale color of sapwood of young teak is recognized usually as a weakness, but this brighter surface can be an advantage, i.e. if this surface is recolored by the more attractive or brighter color of finishing system. The pattern border and the certain direction jointing between sapwood and its heartwood parts also will create the unique visual appearances to increase the interest for wooden products manufacturer, craftsmen, or designer to use these young teaks for making various products.

The properties of a wood usually reflected on its heartwood of mature teak, and this part is the most significant influence and useful in terms of wood utilization [11]. The lower resistance of sapwood compared to its heartwood must be considered properly if sapwood part will be used, i.e. for making products. Understanding to the mechanical properties and the characteristics of the young teaks would be possible to use more appropriate for its occasions, more effective for the physical appearance and more efficient for the using of material.

The result of determination has shown that the young teak has the same strength class with mature teak and therefore basically it is possible to utilize this young teak for the ordinary application as well as the mature teak. Nevertheless, due to the trunk size of young teak that is narrower than the mature teak, therefore the application of young teak should consider for the suitable products according to its limited size. In addition, it is possible to

enlarge the size of young teak, i.e. its thickness or its width, by using of certain wood joint system.

Utilization of young teak without any necessary modifications to its characteristics and properties is also possible as long as the utilization take into consideration to the suitability of young teak for the particular products. It is needed to modify of young teak, especially for its durability, to be similar as well as mature teak by using the certain treatments or processes, both chemical and physical aspects, e.g. seasoning, preservation, heating, coating/finishing system, and then consequently, this young teak can be used in ordinary utilization.

Young teaks is one of the potential wood material for making products, due to the unique characteristics, strength, and its availability in the large number, especially from the thinning. However, young teaks from the thinning, which comprise mostly sapwood, are still not well accepted as useful material because these are considered to have the low value as wood material. This is one of the problems for young teaks especially due to the comprising mostly sapwood. Therefore, further effort is needed to develop and find more suitable for its utilization [10].

4.5 Appendices

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CHAPTER V

APPLICATION OF YOUNG TEAK FOR MAKING PRODUCTS

Teak (mature teak) and also young teak has been using for making various products, but the use of young teaks usually are having the lower price relatively for its products. In Indonesia, many small scale-industry use the young teaks for making product such as, various handicrafts, small statues, bird-cages, small wooden components, and also furniture. This has been much more spreading than the previous use of young teaks that is just as firewood for cooking, especially for the people in the village area and also for some plantation industries, e.g. tea plantation companies for several production process. In the past, the wood from teak has been recognized as the high quality wood for firewood of steam engine of train.

The information about use of teak (mature teak) as material for making products can be traced and recognized from many documents and treasure artifacts, but it is different to the use of young teak. The official document that has reported about the use of young teak for making products is almost rare, and therefore, information about the use of young teak in product is obtained directly from the producers of teak furniture in Indonesia.

Young teak, which mostly comprise of sapwood part, now is exposed to the different color between sapwood and its heartwood parts, because of the interest from some costumers, or it is because of the limitation of teak material (mature teak) at that time and also the high price of mature teak. In the previous era, the use of sapwood part usually is hided, this part is put under the above side/surface of products, because if the customers can recognize

this sapwood part, they will complain and consider these products as the lower quality than the ordinary products in which completely use heartwood parts. During the time, the customers start to interest the use of lighter color (sapwood part), which is combined to darker color of heartwood part in the furniture especially. The customers consider that the combination color between sapwood and its heartwood part is attractive and unique aspect, but it is possible that the customer do not understand about the different strength and durability between mature teak and young teak.

5.1 Recent Research and Application of Young Teak

Young teak has attracted for many related researcher and also wooden product makers because of its potential that is produced from the teak plantations in particular. The reputation of teak as one of the high quality and prominent wood material has been making teak as one of the popular material for substitute of world wood demand. Teak plantation has been predicted will increased during the time [1]. Several countries in which is having appropriate soil condition have been trying to plant teak in their areas, e.g. the area in northern Australia, many areas in Africa and Latin America whereas the tropical Asia is has been starting since early [2].

Beside of the teak plantation management aspects, many researchers interest to assess and determine the properties of teak that is compared to its young teak. Start from the anatomical and physiological aspects until mechanical properties, and the result has been showing that young teaks are having similarity to the mature teak, although in the lower range of strength class, but these teaks can be used for making various products. Mostly

application of these young teaks is made for furniture, because of its contrast attractive color between sapwood and its sapwood parts [3].

For many researchers, color and chemical variation of teak from various age classes is important to be determined. This aspect is related to the durability of teak especially as the most prominent properties. The various colors occur because of the material contents that influence to the properties of teak, i.e., the durability of sapwood and its heartwood for fungi or insects attach, decay resistance, etc. [4]. The result of these research must be continued to the application by taking its prominent characteristics and properties.

5.2 Conceptual Approach for Young Teak Application

Utilization of young teak with mostly part is sapwood, and therefore need the focus to the sapwood part. Utilization of young teak for making products can be divided into two approaches:

1. Modification of sapwood characteristics and properties, especially its durability, to be similar to heartwood by using certain treatments or processes, both chemical and physical aspects, e.g. seasoning, preservation, heating, coating/finishing system, and then consequently, this sapwood can be used in ordinary utilization; and
2. Utilization of sapwood without any necessary modifications to its characteristics and properties, but must be considered to the suitable products.

However, the utilization if take into consideration to the suitability of the unmodified sapwood for particular products, some considerations regarding the use of sapwood of young teak will follow these aspects, such as:

1. Properties of young teak is usually less favorable than this of mature teak, but some research have concluded that the wood properties of teak can be improved, i.e., by implementing of *tree-breeding* program [4];
2. Sapwood of teak is relatively free of extractives, thus *impregnating preservatives* in sapwood by the *pressure* method is likely easier than in heartwood [5], however, sapwood of teak is recognized also has low *permeability* for preservatives [6]; and
3. *Bonding* of teak is recognized as being *most difficult* [7], although this actually refers to the properties of its heartwood, but if the property of permeability for preservative is adapted, it is possible that the sapwood of teaks, like the heartwood, is also difficult for bonding. From the assessment result has been shown that the bonding is possible to be applied for young teak especially.

Many experienced woodworkers and furniture companies use only the heartwood for furniture projects because heartwood is undeniably durable, richer, and more beautiful than sapwood. However, sapwood is also useable if [8, 9]:

1. The wood is dried to a proper level of moisture content, but this process will spend high cost relatively;
2. The wood is used in a project in which shrinking and drying of the wood will not create problems, for example, toys, stationeries, etc.; and
3. The wood is sealed thoroughly using appropriate *finishing system* to increase its durability aspect.
4. By using of appropriate treatments, such as oven-dry seasoning and preservation with pressure, can improve the durability of sapwood to match that of heartwood. Other treatments, such as heating and removing starch and sap use the certain solvents, can

also make the sapwood more durable and usable [10, 11].

According to some research, there is no significant difference in the *strength* between heartwood and its sapwood. This is likely because there are no differences in their structures and there is no changing anatomically. The difference in strength is closely correlated to wood density. The difference recognized only to the content of materials in their cells, which is related to wood durability [12].

The lower resistance of sapwood compared to heartwood must be considered properly if sapwood part will be used for making products and, moreover, for use as structural timber, especially on exteriors that are exposed to the various weather condition.

Sapwood of young teak can be provided from the two resource categories, these are:

1. The young teak logs, which comprise mostly sapwood; and
2. Sawing and re-sawing of teak logs, timbers, or lumbers, which contain proportions of both sapwood and its heartwood. This sapwood is recognized as removed waste material, have not standard size, narrow relatively, and there is an obvious or contrast different figure on the border between sapwood part and its heartwood.



Figure 5.1. Teak logs and teak planks which contain its sapwood parts.

Young teaks from thinning are available and have been used for firewood and also for making products, such as furniture, although with some limitation and relatively weaknesses due to their lower durability, smaller trunk size, bigger shrinkage, bigger distortion, and pale color. Raw material of young teak is provided in huge number from the thinning, therefore, the continuity as wood material is possible sustainable, without any damage to the nature/environment in particularly.

If consider to the characteristics of young teak, from this point of view, based on visual characteristics, sapwood part has the distinctive color than its heartwood part, and based on size of wood trunk, the diameter of young teak is smaller than the mature teak.

There are some contrast colors on the border between sapwood and its heartwood in transverse surface, radial surface, and also in tangential surface. The color intensity near to the borders edges on the heartwood parts also vary, darker and brighter color alternate between *early-woods* and *late-woods* at the growth rings. The result of experiment has shown that the darker color surface appears from the pieces of heartwood part and the lighter color surface appears from the pieces of sapwood part. Caused by the lighter color of sapwood surface, the coloring on sapwood surface will appear more *attractive* and *vivid* than on its heartwood.

The pale color of sapwood of young teak is recognized usually as a weakness, but this brighter surface can be an advantage, i.e. if this surface is recolored by the more attractive or brighter color of finishing system. The pattern border and the certain direction jointing

between sapwood and its heartwood parts also will create the unique visual appearances to increase the interest for wooden products manufacturer, craftsmen, or designer to use these young teaks for making various products.

Utilization of young teak without any necessary modifications to its characteristics and properties is also possible as long as the utilization take into consideration to the suitability of young teak for the particular products. It is needed to modify of young teak, especially for its durability, to be similar as well as mature teak by using the certain treatments or processes, both chemical and physical aspects, e.g. seasoning, preservation, heating, coating/finishing system, and then consequently, this young teak can be used in ordinary utilization.

Teak (mature teak) has been recognize with the high quality and prominent because of it properties and unique characteristics, but this is contrary to the young teak that has the same properties and characteristics if it is compared to another wood species which have sapwood and heartwood part also. In this case, it seems that the significant aspect of the young teaks is only the availability in the big amount from the thinning that can be used as an alternative of wood material resources. From this consideration, it should have to be explored the most suitable application for these young teaks, and not only from the point of view of its quantity but the exploration is possible also from the point of view of esthetics, uniqueness, and the prominent characteristics.

5.3 Practical Product Application

The amount of young teaks from thinning can provide the demand and need of wood for many kind of purpose/function. The practical application of young teak can be categorized such as:

- A. Furniture.
- B. Building Components; including flooring; paneling; beam, plank, veneer, etc.
- C. Tools/Equipment, Kid Toys, Educational Equipment.
- E. Table/Kitchen Wares, Stationeries.
- F. Artworks, Decorative Products/Ornaments.
- H. Special Occasion.
- I. Firewood, et cetera.

Mechanical properties and characteristics of young teaks and its various border patterns are prominent aspects that can be useful in practical application for making products. One of the important aspects also from the assessment results in which can be influent to practical application that the young teak has been recognized can be applied for bonding with satisfactory. This is different with the condition of mature teak that has been recognizes with difficult in bonding usually, because of the contents of oily extractives in its heartwood parts.

The result of assessment to young teak has shown that the young teak has the same strength class with mature teak and therefore basically it is possible to utilize this young teak for the ordinary application as well as the mature teak. Nevertheless, due to the trunk size of young teak that is narrower than the mature teak, therefore the application of young

teak should consider for the suitable products according to its limited size. In addition, it is possible to enlarge the size of young teak, i.e. its thickness or its width, by using of certain wood joint system. Consideration to the application, the wood joint system will be applied for some occasion, e.g.:

1. Enlarging the size of pieces, become wider or bigger; SW/YT that usually smaller/narrower than the mature teak, both in plank/beam size or stump diameter;
2. Increasing the strength of form structure; make the structures become stronger and effective for retain stress or load (effectiveness);
3. Efficiency of material;
4. Increasing of attractiveness, uniqueness, and aesthetics appearance of the products;
5. For specifics intension/occasion: adjustable, arrange-able, knockdown, modular system, assembling (easily dismantled and reassembled)

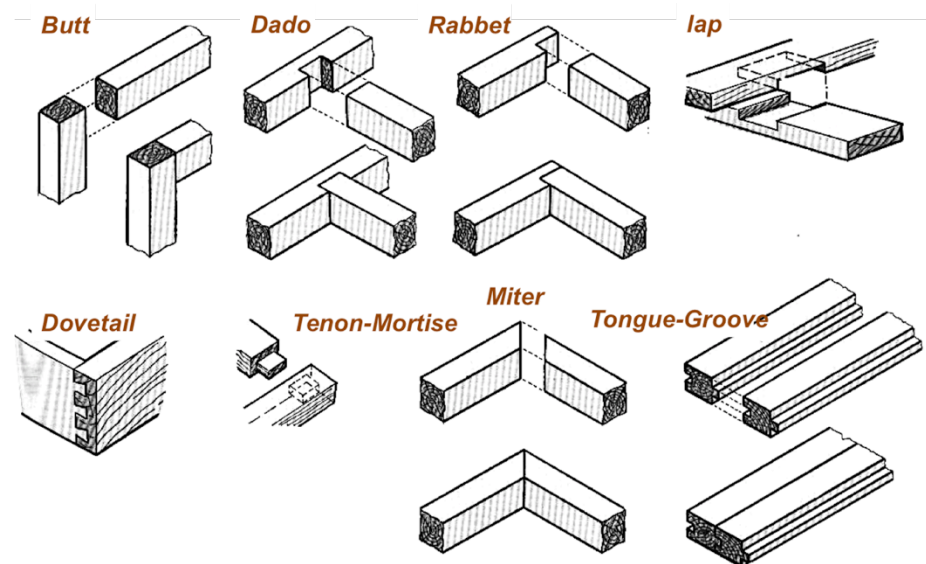


Figure 5.2. Basic type of wood joint system.

Use of young teak is intended for getting the unique/esthetics characteristics of its *border-patterns* between heartwood and its sapwood parts. On the other hand, young teaks also

can be used as a structural wood material, e.g. beams, planks, etc., and the strength is similar with the common teak (mature teak) in general, but with the lighter color of its surface, and the various border patterns between sapwood and its heartwood parts. These characteristics can provides the more spread possibility young teak for practical application.

5.4 Appearance of Border-Patterns Configurations

For getting various patterns among sapwood and its heartwood configuration for making products occasionally, necessarily terms has been introduced to recognize its various configuration categories. Uses the ordinary sawing technique, the conversion of logs into *lumber*, i.e. plain/flat-sawn, billet/rift-sawn, or quarter/grade-sawn, appearance of the border sections between sapwood and its heartwood of teak part in a piece of relative small beam or plank, as is illustrated in Figure 5.3.

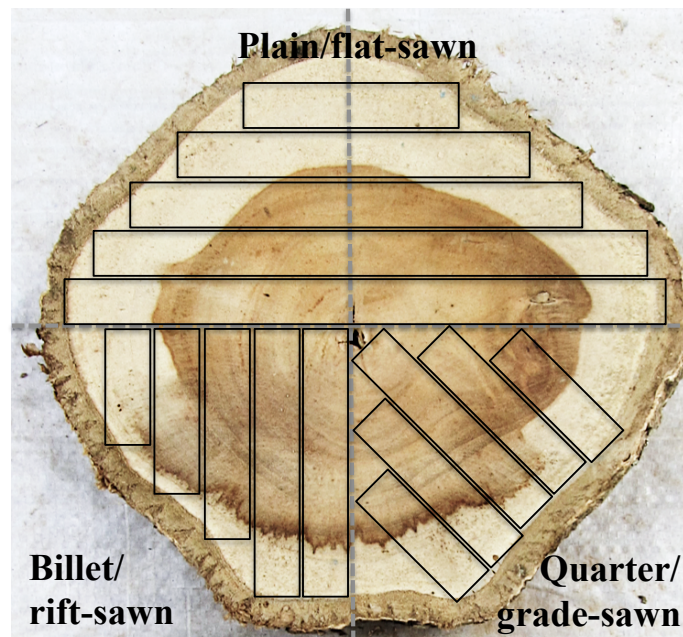


Figure 5.3. Types of basic sawing technique of logs

At the transverse surface that is categorized as parallel section (A) and oblique section (B), whereas at the tangential or radial surface that is only parallel section (C) can be produced from these sawing technique. The two types of these border sections, parallel section and oblique section, are relative as the direction section at the transverse, tangential, and radial surfaces on a beam or a plank.

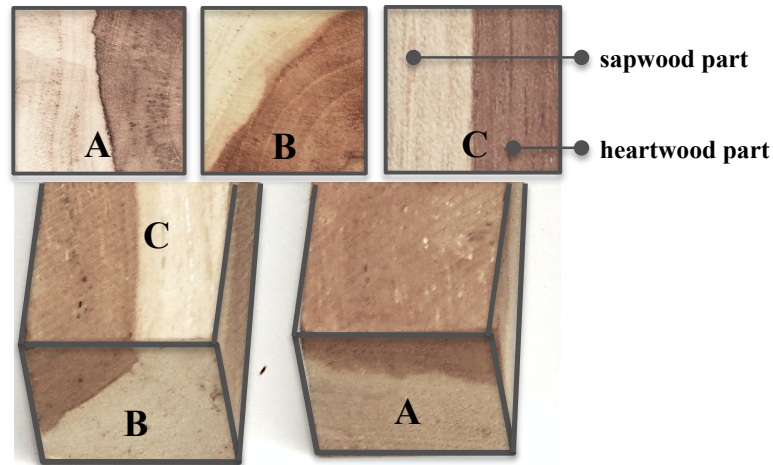


Figure 5.4. Types of border section: parallel-section (A, C) and oblique-section (B) at transverse (A, B) and at tangential or radial surfaces (C) on a beam or a plank

Several pieces of beam or plank, which is having the certain type of border-section, are jointed as *face/flat* or *edge-grain to face/flat* or *edge-grain* joint system, and to be configured, in this case is shaped as *square* or *rectangular*, become a larger or wider pieces. These configurations can be categorized become two type of configuration as parallel-sections configuration and oblique-sections configuration. These two configurations are having several alternatives that can be applied both for parallel section and oblique section. Eight basic types of configuration, both of parallel-sections configuration and oblique-sections configuration have been created as it is described in Table 5.1 and it is illustrated in Figure 5.5 and Figure 5.6. It is possible to create another type of configurations more than these sixteen basic types according to the needs.

Table 5.1. Terms for basic type of border-sections configurations

1. Parallel-Sections Configuration		2. Oblique-Sections Configuration	
A	Centered Light	A	Centered Light
B	Centered Dark	B	Centered Dark
C	Parallel Line	C	Halved
D	Parallel Checkered	D	Crisscrossed
E	Square Checkered	E	Cornered
F	Square Line	F	Striped
G	Axisymmetric Light	G	Multidirectional
H	Axisymmetric Dark	H	Directional

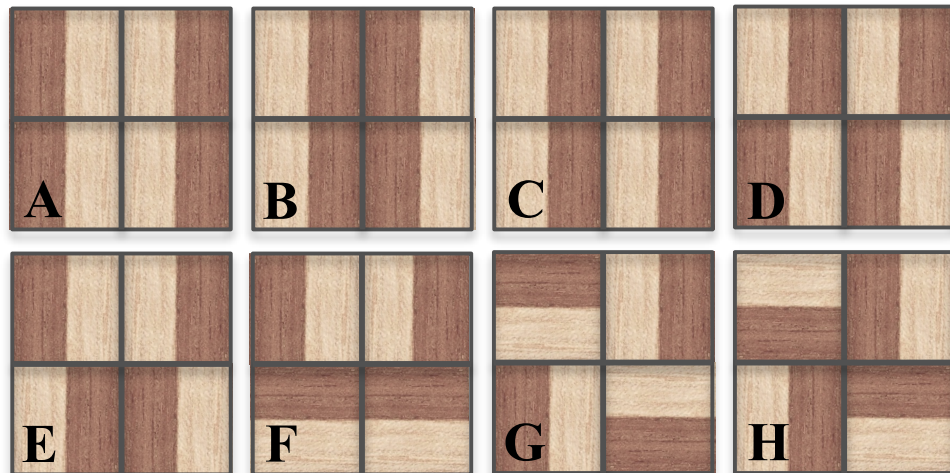


Figure 5.5. Eight basic types of parallel-sections configuration on a square

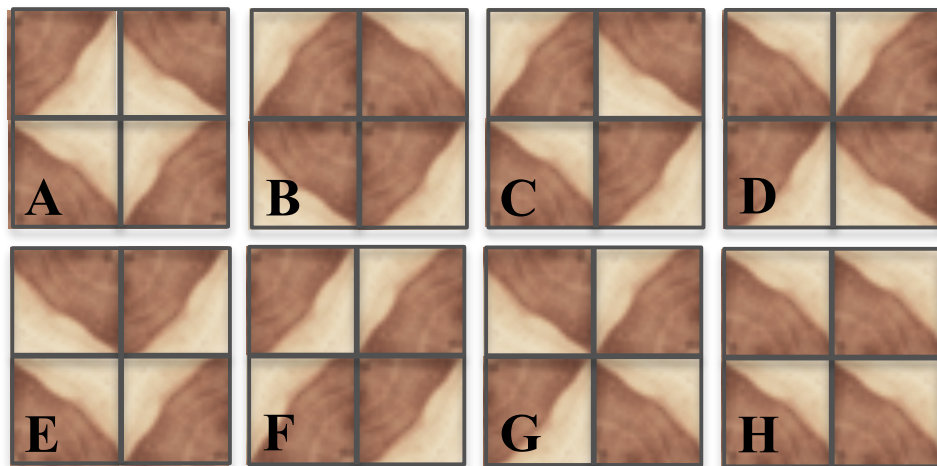


Figure 5.6. Eight basic types of oblique-sections configuration on a square

Various configurations are generated from the variation of *border-sections* composition (parallel-section or oblique-section), position (above, below, side, and turn to the left or right), and shape (square, rectangular, or other forms) of its pieces/parts in a certain configurations, and therefore the more various configurations is possible to create more than those previous sixteen basic types.

These border-sections configurations may be recognized as similar technique and appearance in which is basically use the geometric mosaic just like in parquetry or marquetry, but the most prominent in these configuration technique that the patterns are created mostly by the difference of contrast color among border patterns of sapwood and its heartwood parts in the certain configurations. This technique can be considered which is close to the technique for creating and matching of veneer patterns. The difference between those techniques is in the use of sapwood and its heartwood border patterns in contrast to the grain patterns in veneer [13].

The number of each basic type *parallel* or *oblique-sections configuration* parts, can be added respectively, and its position can be rotated symmetrically, i.e. rotation of 90^0 , 180^0 , or 270^0 to each parts alternately, for creating more various unique patterns as the decorative effect. For this example, after adding and rotating to some parts, this visual appearance may be recognized as similar to the *basket-weave*, one of parquet flooring patterns, as it is illustrated in Figure 5.7 for two of the *parallel-section configurations*

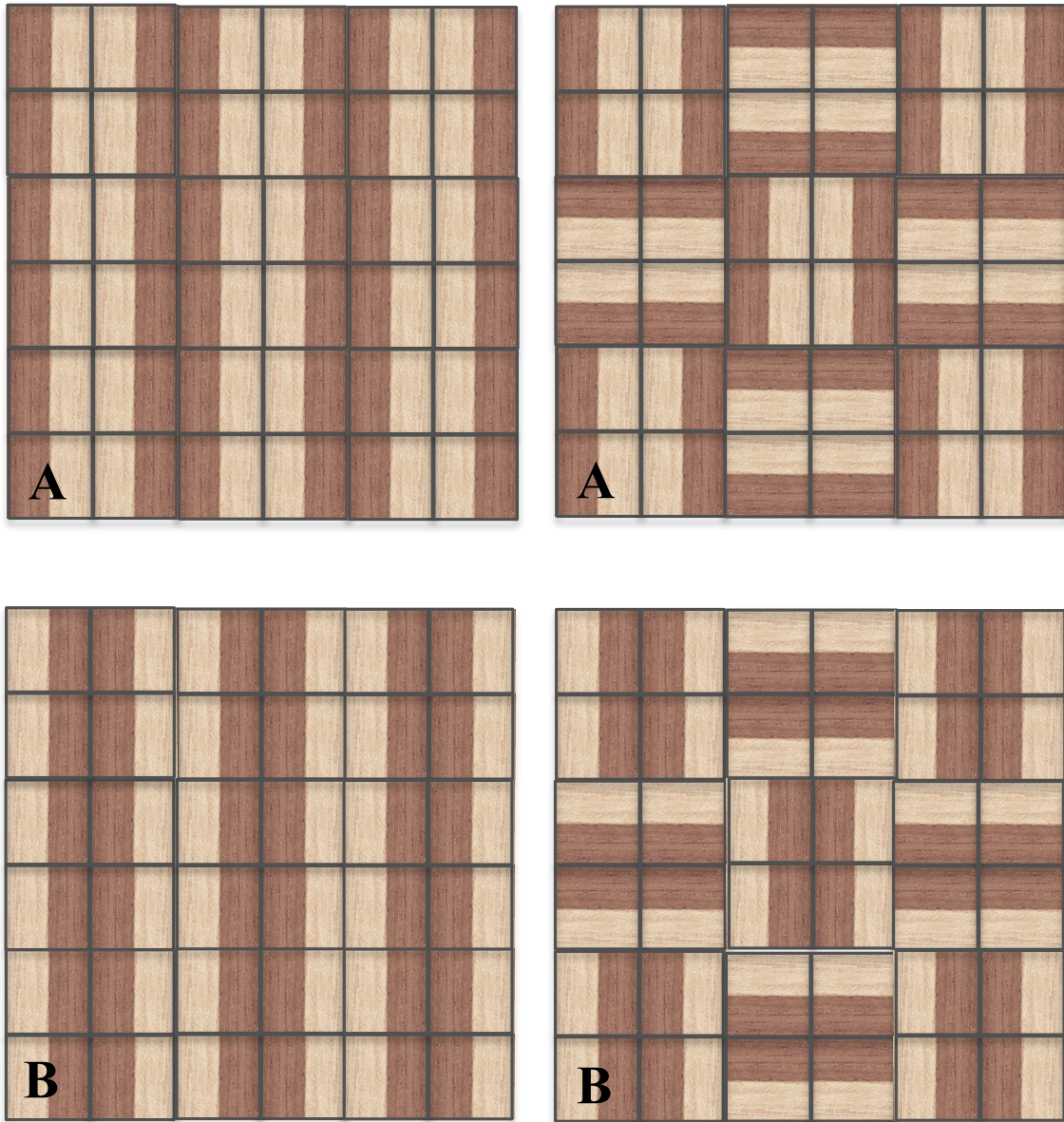


Figure 5.7. Example of multiple adding and rotating to two types of parallel-sections configurations

5.5 Appearance of Configurations for Products

In practical application, all of the various *border sections configurations* are possible to be applied for making various products or components, such as parquet-floorings, panels, furniture or building components, structural beams or plank, et cetera, or it is possible also to be utilize directly as raw material for making various products, both of functional

products and non-functional/decorative products. In this session, the number of application of *border-sessions configurations* for the products/components will be displayed. In Figure 5.8, it is the examples of application from the configuration/mixing the numbers of *oblique-sections configuration* and *parallel-sections configurations*, i.e. type of *parallel line* (1-C), *parallel checkered* (1-D), and *centered dark* (2-B), for create parquet flooring. Occasionally, it is possible to choose, which one of the sides will be used, because both of the sides (top side/surface or bottom side/surface) of the parquet/part mostly are having different appearance, as shown at Figure 12.

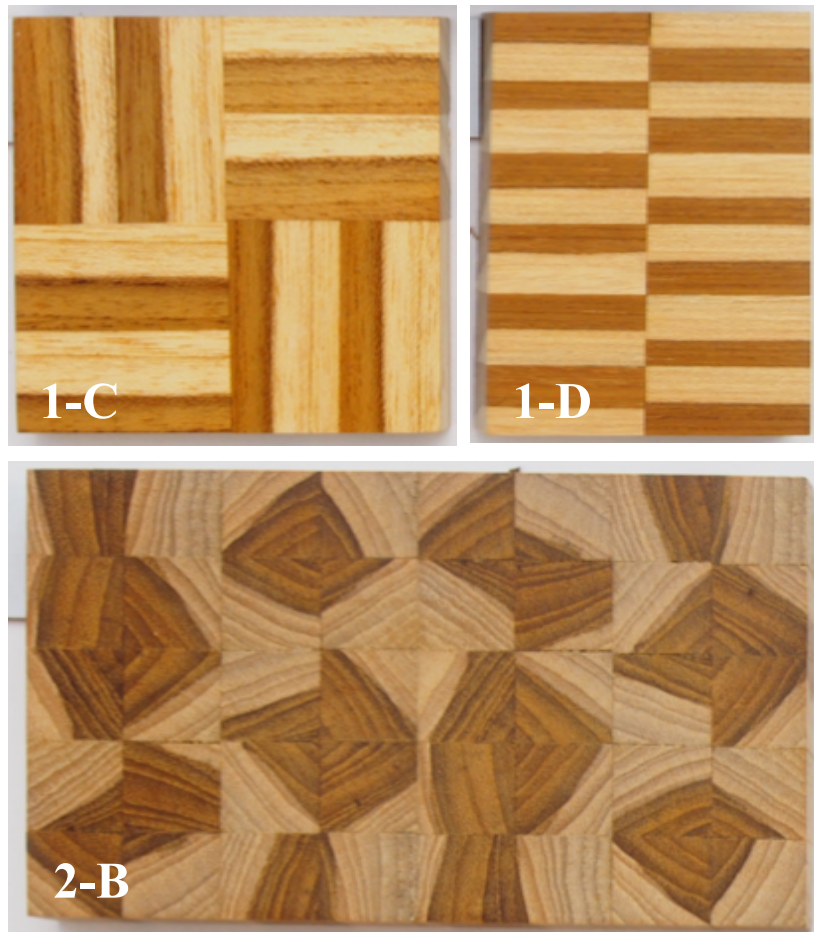


Figure 5.8. Parquet-flooring use *parallel-sections* and *oblique-sections configuration*; *parallel line* type (1-C), *parallel checkered* type (1-D) and *centered dark* type (2-B)

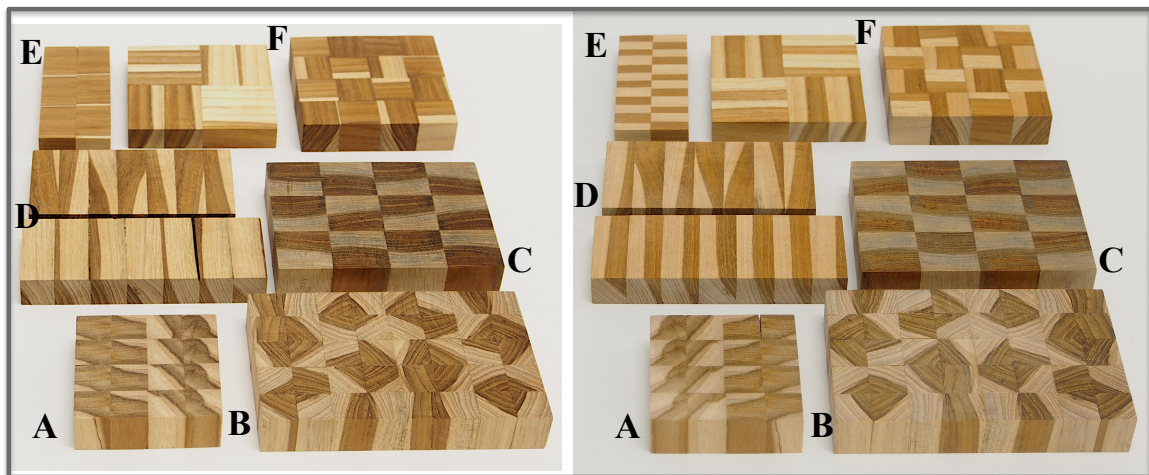


Figure 5.9. Two side characters of Parquet-flooring from various border-patterns configurations

In Figure 5.9, pieces A, B, and C are the transverse surfaces, pieces D, E, and F are the radial and tangential surfaces. Bonding with wood-glue. Each face of all these pieces surfaces are different each other relatively. Patterns appear due to the combination of the different border color between sapwood and its heartwood parts.

Character of these borders-patterns can be used for wood *joint system* also. One of the functions of wood joint system application is to get the wider or thicker size of beam or plank for many occasions. The purpose of these combination border-patterns of sapwood and its heartwood parts in this joint system is intended for obtaining the unique appearances than to its structural strength. Use of two pieces or more of parallel-sections as components of joint system can be created the different choices for color surface appearance. The different color derives from the color of sapwood and its heartwood parts as shown in Figure 5.10.



Figure 5.10. Application of *parallel-sections* (transverse surface) for *tongue-and-groove* (left side) and *dovetail* (right side) wood joint system for getting the different color combination of surface appearance

At figure above, that *tongue-and-groove* and *dovetail* joint can be composed for having the three various combination color appearance. The surfaces color can be dark, bright, or its combination. Another border patterns will appear with different characters occasionally, according to the type of its configuration in which is used.

Configuration of *border-sections* can be applied as raw material for making wood-lathe wooden products, i.e. for making small pole/pillar (rounded piece of wood), for furniture or building component, and for making rounded wooden products, e.g. cup, dishes/plates, et cetera. The unique appearance will create by the certain of those borders-patterns configuration, and in this case, e.g. configuration of *centered light* (2-A) and *centered dark* (2-B), as shown in figure 5.11 and Figure 5.12.



Figure 5.11. Small pillar, wood-lathe product, which is created from the *centered light* type (2-A) of *oblique-sections configuration*



Figure 5.12. *Centered dark type (2-B) of oblique-sections configuration* as raw material for making small cup of wood-lathe product

In Figure 5.11 and Figure 5.12, the certain pattern will appear on the surface of these products because of the different arrangement among the pieces for making the certain configuration/combination. In these samples, the most unique pattern will appear if the arrangement of each piece is *centered* or diagonal between sapwood and its heartwood part, and than these pieces are glued face to face across from each other. The certain unique patterns will appear after the pieces are processed use the wood-lathe process.

Light surface of young teak, i.e. sapwood parts, for new coloring as a chance to change the image of teak as and old fashion into new style, brighter, and colorful. This application will be suitable for toys product or products with the modern style. Base on mechanical properties, unique border of sapwood and its heartwood part, bonding character and the application of joint system, some practical applications has been made to utilize of young

teak. Those products are intended become component of various products, such as for furniture, building, toys, kitchenware, et cetera.



Figure 5.13. Wood lathe products with its border-patterns configuration

5.6 Relation to the Wooden Products Industry in Indonesia

In Indonesia, teak (mature teak) and also young teak are used for making various products, but the use of young teaks usually are having the lower price relatively for its products. Many small scale-industry use the young teaks for making products such as, various handicrafts, small statues, bird-cages, small wooden components, and also furniture. This

has been much more spreading than the previous use of young teaks that is just as firewood for cooking, especially for the people in the village area and also for some plantation industries, e.g. tea plantation companies for several production process. In the past, the wood from teak has been recognized as the high quality wood for firewood of steam engine of train.

The information about use of teak (mature teak) as material for making products can be traced and recognized from many documents and treasure artifacts, but this is different to the use of young teak. The official document that has reported about the use of young teak for making products is almost rare, and therefore, the information about young teak that is used in products is obtained directly from the producers of teak furniture in Indonesia. They use the young teak, which mostly comprise of sapwood part, by making exposed to the different color of sapwood and its heartwood part for getting the unusual appearance/pattern of surface. Demand or interest to young teak furniture it has been transpiring since about five - ten years ago.

There are some buyers are getting interest also for buying the furniture in which uses young teak due to the combination color of its sapwood and heartwood parts. On the other hand, or it is because the limitation of teak material (mature teak) at that time. In the previous era, the use of sapwood part actually is hided, this part will be put under the above surface of products, because if the buyers can recognize this sapwood part, they will complain and consider these products as the lower quality than the ordinary products in which completely use heartwood parts. During the time, buyers start to interest the use of lighter color (sapwood part), which is combined to darker color of heartwood part in the

furniture especially. Buyers consider that the combination color between sapwood and its heartwood part is attractive and unique aspect.

There are more than 4,000 small and medium enterprise of furniture industry in Indonesia, and the presence of wooden product industries has contribute significantly to the nationwide income and economics, and obviously also for providing of labor absorbing in particular. According to the data from AMKRI (Asosiasi Mebel dan Kerajinan Indonesia; translated: Indonesia Furniture and Handicraft Association), in 2011, furniture and home wares sale for domestic market are estimated more than US\$700 million, while the worldwide export market is US\$2.2 billion, and increase during the time, in 2013 become US\$2.6 billion. AMKRI aims to reach US\$5 billion in export within the next 4 years as long as the government policies, supply of materials, skilled producers, etc., are working continuously and supportive one another for pursuing that target. The world furniture exports currently is US\$144, and Indonesia only contribute around US\$1.8 billion. This market is predicted will increase in the future [14, 15].

Teak is one of main wood material for export products, beside the other wood, such as mahogany, keruing, et cetera, in this case, young teak from the thinning is one the potential materials that can provide and also substitute that wood material in demand to enlarge the production capacity, especially for export market.

In one the biggest area of furniture and wooden products industry in Indonesia, e.g. Jepara City in Central Java Province, Indonesia, there are 15,271 unit industries, that is categorized as home industry, small, medium, and large units categories, are have been

identified and it is having employing approximately 170.000 workers. The activities generate revenue more than US\$ 1 billion per year. The district of Jepara consumes between 1.5 - 2.2 millions m³ of round-wood annually, and teak is the main material that is used for making products in this area [16].

Wooden craft industry is worth US\$ billions of dollar annually and has been providing for 100's thousand workers in this sector. Most of the producers are small and medium-sized enterprise that are spread all over the country, but mostly in the rural areas. The craft has developed to become a fully mature commercial industry. In addition to satisfying local markets, the products have been exported to many countries in the value of millions of dollar annually, creating prosperity along the way. With the help of technology and globalization, craftsmen now have varying material at their disposal. With their highly creative mind, the potential is limitless. On the demand side, buyers from all over the world now can also buying these products directly. Statistical data shows that the export of statuettes and other ornament of woods was more than US\$0.5 billion annually. Other wooden items, e.g. wooden frames and casket and similar items, have similar export value. For all of those items, Indonesia is the leading world supplier [17].

Indonesia is having many areas as a center of production that has been producing wooden products, especially classified as handicraft, carving, furniture, tableware, kitchenware, building component, et cetera. The export values from these products are still increasing from time to time. Woodworking is the process of creating, making or carving something using wood. As the place one of the largest tropical forest area in the world, wooden industry is the one important and strategic for Indonesia. In while many big companies are

involved in timber, plywood, paper and pulp, and furniture, wood-based handicraft industry usually involved the small businesses, especially home industries. Many of the products are consumed domestically (e.g. for home decorations, religious usage, tableware, et cetera), but more are exported. In this aspect, the industry is also related to the tourism industry, and empowerment of the society [17]. Consider to the strategic existence of wood industries in Indonesia in particular, it is hoped that the potency of young teak from the thinning can supply the demand of wood and can be the substitution material for the local of small and medium wood industries especially, for getting the advantage to social empowerment and economical point of view.

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CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 General Conclusions of Wood as Natural Material

Wood (*solid wood or timber*) is one of the natural materials that can be growth. With its renewable and grow-able characteristics, and for this reason in the future, wood is expected to be one of the potential substitute materials for replacing of non-renewable materials. In addition, because of its natural characteristic, wood is an environmental friendly material and easy to recycle (degradable and recycle-able), its relatively safe and harmless to the environment.

Various types of wood have a diversity of its properties and characteristics. Each wood has a different of versatile potency, both in terms of its technical and aesthetical aspects. Many kind of wood have been using for making of various functional products those we use today, starting from traditional and simple until modern and complex products, from various of handicrafts products, furniture, until house and the structure of buildings.

Nevertheless, a number of weaknesses and problems exist in wood, according to their characteristics. For example, wood could be damaged by the destructive pests such as insects and fungus, it can not resist to the weather change, it has a heavy weight and limited strength relatively in comparison with the other materials which are milder but relatively can be more powerful than wood.

Currently, in Indonesia particularly, there are many small-scale industries, as a part of Small Medium Enterprise (SME), but the scope is more specific, engaged to the

manufacturing of wood products. Various products have been making and selling, both locally and for export markets commodity. This industry's sector is one of the important aspects in the economical point of view, thus it should be encouraged to grow and develop in Indonesia. I consider to Indonesia as one of country that has the potential large of wood resources relatively. With the existing land and properties of wood that can grow well in Indonesia, this great potential needs to be managed and developed optimally, especially in the future.

For making wood became one of the potential material in the future, wood should be developed into raw material for a product which according to demands of development and age, both in terms of functionality, technical, until the aesthetic aspects. Wood also can be a substitute for other material that is difficult to be obtained, more dangerous for the environment, or more expensive, etc. in the future.

However, in addition to the wood utilization problem that can be made into various products in the future, but we also have to keep thinking of forests existence and their wood for keeping a comfort environment and save to the earth. Thus the using of wood into various products must be done wisely and optimally with consideration to the problems of environment and earth.

There are many valuable lessons that will be obtained about how the wood optimally utilized and processed into a product, from selection of suitable wood materials, production processes which are effective and efficient, appropriate and adequate of wood joint systems, until high-quality finishing processes. Thus, the resulting products have a

reliable practical function in addition, also can show a high aesthetic values and accordance with the demands and the spirits of the era.

6.2. Conclusions and Recommendation for Young Teak Utilization

The properties and the characteristics of wood differ between species of tree. These aspects mean that a certain wood is often more suitable for specific application and for making certain products, and designing for products development in this case are required to produce the suitable and quality products [1, 2]. This aspect is also can be applied for the young teak.

Information regarding to the characteristics and properties of teak usually refers to its heartwood. This is because the heartwood of teak is the most valuable and important part for its utilization and commercial purpose. In the past, the sapwood was never really considered useful, because teaks were typically felled at mature age (old-growth age) and the amount of remaining sapwood in these older trees was not significant. Now, however, due to the thinning, there are a large number of young teaks with the greater parts are sapwood. This potential material can be an alternative material for making products. Utilization of young teaks which mostly comprise sapwood is necessary when consider its high availability from the thinning of teak plantations especially and the increasing of the global demand to the wood.

Young teaks from the thinning, which comprise mostly sapwood, are still not well accepted as useful material because these are considered to have the low value as wood material. This is one of the problems for young teaks especially due to the comprising

mostly sapwood. Therefore, further effort is needed to develop and find more suitable for its utilization [3].

The properties of a wood usually reflected on its heartwood of mature teak, and this part is the most significant influence and useful in terms of wood utilization [4]. The lower resistance of sapwood compared to its heartwood must be considered properly if sapwood part will be used, i.e. for making products. Understanding to the mechanical properties and the characteristics of the young teaks would be possible to use more appropriate for its occasions, more effective for the physical appearance and more efficient for the using of material.

Based on this research results, there is no significant difference in the strength between heartwood and its sapwood. The result of determination has shown that the young teak has the same strength class with mature teak and therefore basically it is possible to utilize this young teak for the ordinary application as well as the mature teak. Nevertheless, due to the trunk size of young teak that is narrower than the mature teak, therefore the application of young teak should consider the suitable products according to its limited size. In addition, it is possible to enlarge the size of young teak, i.e. its thickness or its width, by using of certain wood joint system.

The pale color of sapwood of young teak is recognized usually as a weakness, but this brighter surface can be an advantage, i.e. if this surface is recolored by the more attractive or brighter color of finishing system. The various border-patterns between sapwood and its heartwood parts uses the certain configurations will create the unique visual appearances

to increase the interest for wooden products manufacturer, craftsmen, or designer to use these young teaks for making various products.

Some companies and individuals have been producing various products that use young teaks [5]. However, there is untapped potential for further utilization and new products development use young teaks, which comprise mostly sapwood. It is necessary to consider the use these potential materials without any extraneous and high-cost processes. Therefore, developing the most suitable products that match to the properties and prominent characteristics of this sapwood is more appropriate to enhance their utilization and value in the future, and also without any resistance from the environmental issues especially.

For obtain the ultimate results, it is needed to modify of young teak, especially for its durability, to be similar as well as mature teak by using the certain treatments or processes, and then consequently, this young teak can be used in ordinary utilization. Nevertheless, utilization of young teak without any necessary modifications to its characteristics and properties is also possible as long as the utilization take into consideration to the suitability of young teak for the particular products, and therefore, developing the most suitable products that match to the characteristics and its properties of young teaks is more appropriate to enhance their values at the present and in the future.

This research approach and methods which have been applied to the young teak as case study is possible practicable also to apply for another wood species in which comprise sapwood and heartwood part in their wood trunk, e.g. Japanese Cedar/*Sugi* (*Cryptomeria*

japonica. Further research must be needed to conduct the assessment for the durability properties of young teak in particular, and the research should be continued to make the latest and complete properties and characteristics of young teak in particular.

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ATTACHMENTS

A. Properties and Characteristics of Teak

Weight Density: 0.67 - 0.75 gr/cm ³ (Strength Class II: 0.60 - 0.90 gr/cm ³) [35].
MOR: 101.106 MPa and MOE: 12.523 GPa (Strength Class II: 71.098 - 107.87 MPa) [35].
Durability Class II: 5 years contact with wet soil, 15 years at outdoor with normal weather, unlimited at under the roof and dry condition [35]. Very durable with respect to decay and insect attack, and extremely resistant to preservative treatment [11].
Shrinkage: small relatively, from green (>12% MC) to oven-dry (0% MC) is 2.5%% for radial, 5.8 for tangential, and 7.0 % for volumetric [11].
Well seasoned but rather slowly [21].
Color: yellow brown to rich brown, streaks of dark color frequently, become graying at outdoor exposed condition; Odor: unpleasant, leather odor when freshly cut; Grain: fine, straight grain; Surface: oily feel; and Silica content is variable, up to 1.4% (cause the dulling effect) [58].
Bonding ease: bonding with difficulty; satisfactory results require careful selection of adhesives and very close control of bonding conditions; may require special surface treatment [20].

B. Preparation and Process of Specimens Making



Teak Plantation Field Survey



Teak Felling and Sawing



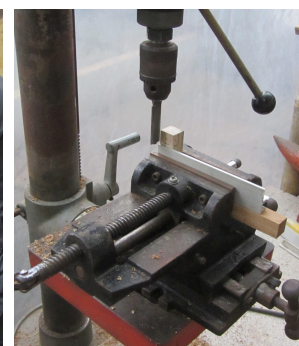
Teak Storage Area



Air Drying



Specimens Making



C. Specimens and Type of Testing



Static Bending, Compression, Tension, Cleavage, and Shearing Test



Type of Specimens; Humidity, Temperature, and MC Meter; UTM Ibertest



D. Specimen Test Data Sheet for Type of Testing A until G

A. Static Bending Strength



Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.1 inch/min (2.54 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26°C - 27°C
Size/Volume (width x depth x length)	20 x 20 x 300 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Modulus of Rupture (MOR) (kgf/cm ²)	Modulus of Elasticity (MOE) (kgf/cm ²)
Standard		0.67		1,031.00	127,700
1	33 H	0.69	196.3	1,030.57	115,762
2	29 H	0.69	179.6	942.90	84,987
3	29 S	0.62	161.4	847.35	94,619
4	18 H	0.60	196.8	1,033.20	108,616
5	18 S	0.64	218.0	1,145.02	115,536

Note: H = Heartwood; S = Sapwood
 Standard MOE for wood: 110,000 - 160,000 kgf/cm² (11 GPa - 16 GPa)

B. Compression Strength Parallel to grain
Maximum Crushing Strength (MCS)



Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.024 inch/min (0.6 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ⁰ C - 27 ⁰ C
Size/Volume (width x depth x length)	20 x 20 x 80 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
Standard		0.67		550
6	33 H	0.69	1847.1	461.77
7	29 H	0.69	834.7	208.67
8	29 S	0.62	789.7	197.42
9	18 H	0.60	211.4	52.85
10	18 S	0.64	1982.7	495.67
10A	30 H	0.60	611.4	152.85
10B	30 S	0.64	1331.7	332.92

Note: H = Heartwood; S = Sapwood

C. Compression Strength Perpendicular to grain

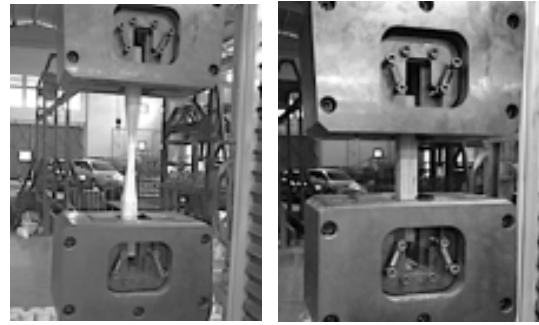


Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.012 inch/min (0.305 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ⁰ C - 27 ⁰ C
Size/Volume (width x depth x length)	20 x 20 x 60 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
Standard		0.67		
11	33 H	0.69	985.9	246.5
12	29 H	0.69	959.7	239.9
13	29 S	0.62	496.1	124.0
13A	18 H	0.60	662.2	165.5
13B	18 S	0.64	628.9	157.2

Note: H = Heartwood; S = Sapwood

D. Tension Strength Parallel to grain



Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.05 inch/min (1 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ⁰ C - 27 ⁰ C
Size/Volume (width x depth x length)	20 x 20 x 300 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
21	33 H	0.69	1062.3	1062.3
48	33 H	0.69	901.9	901.9
22	29 H	0.69	666.6	666.6
23	29 S	0.62	932.1	932.1
49	18 H	0.60	1008.5	1008.5
50	18 S	0.64	1045.4	1045.4
24	33 H T	0.69	101.4	24.35
25	33 H P	0.69	88.6	22.15
51	33 H P	0.69	90	22.50
52	33 H P	0.69	114.1	28.52
53	29 H P	0.69	168.7	42.17
26	29 S P	0.62	170.7	42.67
54	29 S P	0.62	152.2	38.05
55	AL 1 P	0.33	140.5	35.12
56	AL 2 P	0.33	118.2	29.60

Note: H = Heartwood; S = Sapwood; T = glue-Teakbond; P = glue-PVAc; AL = Albasia

E. Tension Strength Perpendicular to grain



Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.10 inch/min (2.5 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ^o C - 27 ^o C
Size/Volume (width x depth x length)	35 x 20 x 40 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
27	33 H	0.69	190.9	47.72
28	29 H	0.69	239.3	59.82
29	29 S	0.62	275.3	68.82
31	18 H	0.60	339.7	84.92
32	18 H	0.60	281.4	70.35
33	18 S	0.64	222.5	55.62
34	18 S	0.64	214.5	53.62
57	K 1	0.59	242.6	60.65
58	K 2	0.59	226.0	56.50
59	AL 1	0.33	102.8	25.70
60	AL 2	0.33	81.1	20.27
35	33 H P	0.69	176.0	44.00
36	33 H T	0.69	187.3	46.82
38	29 H P	0.69	134.5	33.62
37	29 S P	0.62	191.3	47.82
39	18 H P	0.60	227.2	56.80
40	18 S P	0.64	162.0	40.50
61	K 1 P	0.59	102.4	25.60
62	K 2 P	0.59	100.4	25.10
63	AL 1 P	0.33	75.7	18.92
64	AL 2 P	0.33	55.0	13.75

Note: H = Heartwood; S = Sapwood; T = glue-Teakbond; P = glue-PVAc; AL = Albasia; K = Kamfer

F. Cleavage Strength Parallel to grain

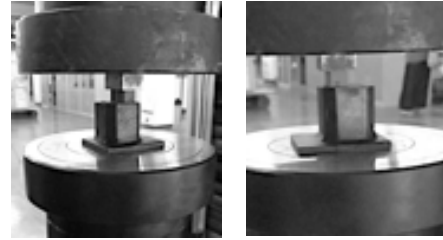


Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.10 inch/min (2.5 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ⁰ C - 27 ⁰ C
Size/Volume (width x depth x length)	35 x 20 x 30 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
41	33 H	0.69	92.0	23.00
42	29 H	0.69	89.1	22.27
43	29 S	0.62	74.4	18.60
45	33 H T	0.69	44.4	11.10
44	33 H P	0.69	27.8	6.95
46	29 H P	0.69	40.8	10.20
47	29 S P	0.62	61.2	15.30

Note: H = Heartwood; S = Sapwood; T = glue-Teakbond; P = glue-PVAc

G. Shearing Strength Parallel to grain



Date of Test	March 28 th , 2013
Laboratory	Structure Engineering Laboratory - ITB
Machine/Device	Ibertest, series Eurotest - 200, Spain, 2012
Speed of Testing (<i>displacement control</i>)	0.24 inch/min (0.6 mm/min)
Load Control (<i>load increasing</i>)	10 kgf/s
Relative Moisture	59% - 60%
Temperature	26 ⁰ C - 27 ⁰ C
Size/Volume (width x depth x length)	20 x 20 x 30 mm ³
Moisture Content (<i>max. 20%</i>)	Radial: 15% - 19%; Tangential: 16% - 19%

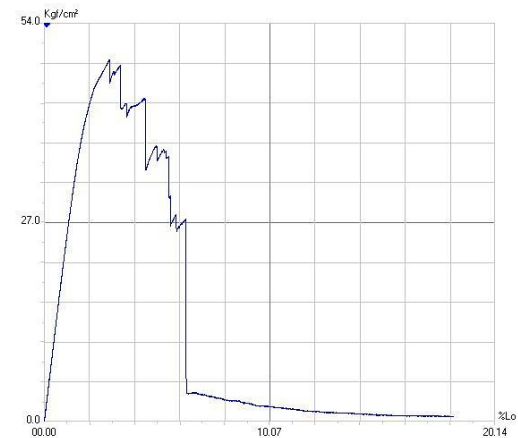
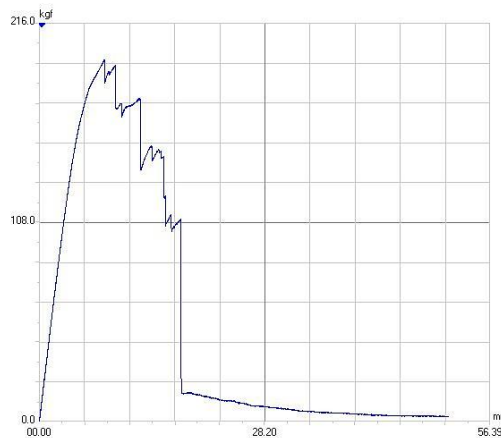
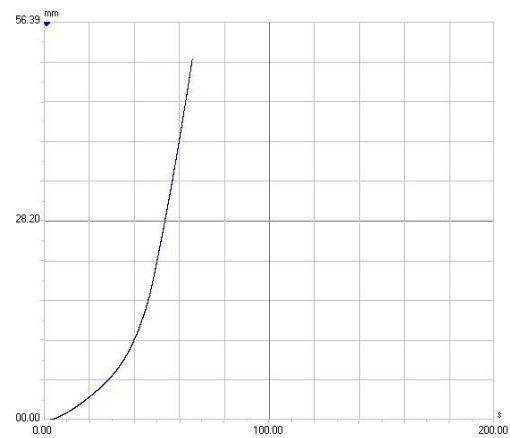
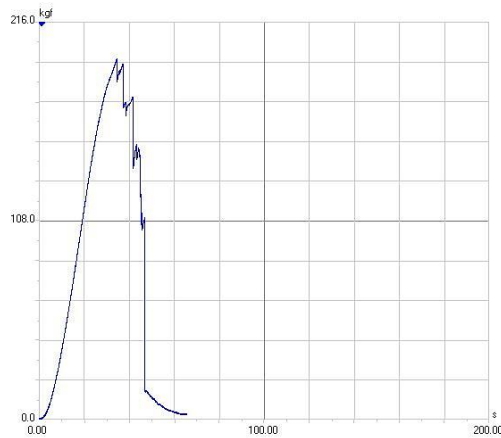
Test No.	Specimen ID	Weight Density (gr/cm ³)	Max. Load (kgf)	Maximum Load to Area (kgf/cm ²)
14	33 H	0.69	552.5	138.12
17	29 H	0.69	695.4	173.85
18	29 S	0.62	572.2	143.05
15	33 H T	0.69		
16	33 H P	0.69	134.5	33.62
19	29 H P	0.69	536.9	134.22
20	29 S P	0.62	390.3	97.57

Note: H = Heartwood; S = Sapwood; T = glue-Teakbond; P = glue-PVAc

E. Set of Data from UTM for each Test Result

A. Static Bending; Reference: 1 – 33 H

Field	Value	Unit	Colour
Date of test	28/03/2013 14:55		
Test max. load	196.3	kgf	
Test max. strength	49.1	Kgf/cm ²	
Maximum position	51.264	mm	
Reference	1		



Time(s)	Load(kN)	Position(mm)
0.1079998	0.00825	3.68E-04
0.1300001	0.00825	3.49E-04
0.152	0.00675	3.49E-04
0.1739998	0.00675	3.49E-04
0.1960001	0.00825	3.49E-04
0.2179999	0.0055	3.49E-04
0.2399998	0.00825	3.49E-04
0.2620001	0.00825	3.49E-04

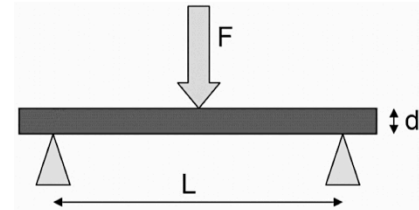
0.2839999	0.00825	3.49E-04
0.3059998	0.00675	3.49E-04
0.3280001	0.00675	3.49E-04
0.3499999	0.00675	3.49E-04
0.3719997	0.00675	3.49E-04
0.3940001	0.0055	3.49E-04
0.4159999	0.00825	3.49E-04
0.4379997	0.00825	3.49E-04
0.46	0.00825	3.68E-04

F. Equation and Conversion Unit

$$\text{Stress} = \frac{\text{Load}}{\text{Area}} = \frac{F}{bd}$$

Using classical beam formulas and section properties, for rectangular sample of specimen under a load in a three-point bending setup, the resulting stress under an axial force is given by the following formula:

$$\text{Bending Stress} = \frac{3FL}{2bd^2}$$



Bending stress is equal with Modulus of Rupture (MOR)

$$\text{MOR} = \frac{3FL}{2bd^2}$$

F = Load/Force (kgf)

L = Length of support span (cm)

b = width (cm)

d = depth or thickness (cm)

y = deflection at load point (cm)

, and its Modulus of Elasticity (MOE) is following this formula:

$$\text{MOE} = \frac{FL^3}{4bd^3y}$$

Measurement unit conversion from N to kgf.

Note: Gravitation is $G = 9.8 \text{ m/s}^2$

$\text{N} = \text{kg} \cdot \text{m/s}^2$

$$\begin{aligned} \text{Pa} &= \text{N/m}^2 \\ &= \text{kg} \cdot \text{m/s}^2 : \text{m}^2 \\ &= \text{kg/m/s}^2 \end{aligned}$$

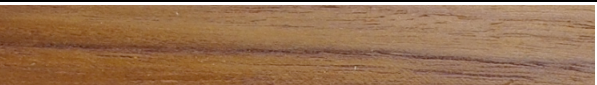
$$1 \text{ Pa} = 1 \text{ N/m}^2$$

$$1 \text{ MPa} = 100 \text{ N/cm}^2$$

$$1 \text{ MPa} = 10.19716213 \text{ kgf/cm}^2$$

$$100 \text{ N/cm}^2 = 10.19716213 \text{ kgf/cm}^2$$

G. Various Color Surface of Teak after Coloring

No	Teak	Surface Color
1	HW (mature)	 <i>original color</i>
2	HW (young)	
3	SW (young)	
4	HW (mature)	
5	HW (young)	
6	SW (young)	
7	HW (mature)	
8	HW (young)	
9	SW (young)	
10	HW (mature)	
11	HW (young)	
12	SW (young)	
13	HW (mature)	
14	HW (young)	
15	SW (young)	