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Development of Mechanical Properties of Softwood using Microwave Drying

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Abstract

The use of softwood has to be increased over hardwood due to its properties, characteristics and mostly availability. The wood industry has been using various drying methods to develop the properties in the wood. To reduce the drying time, microwave heating method was used in this experimental work because of its less drying time and uniform heating. In this study, para rubber wood was dried to pre-determined moisture content using microwave heating in conventional microwave oven. The heating was done at three different heating power and variation in the mechanical properties was observed. The results for compression test along the grains, perpendicular to the grains and for bending strength were compared for the different power settings. A different pattern in the variation of wood properties were observed with respect to the power.

Keywords: Microwave heating, softwood, drying time, compressive strength, bending strength.

1. Introduction

Wood has been used as a building material and the fact is wood has huge environmental benefits over other building products. It is completely biodegradable, works as an effective insulator, and is 100 percent renewable. Because of photosynthesis and its water conducting capability by vessels, it contains significant amount of water and can be consider as a wet porous solid. Wood is usually dried to a moisture content that is close to the average EMC (Equilibrium moisture content) conditions to which it will be exposed which improves its mechanical strength, stability, reduces its weight for easy transport and prepare it for Industrial processes [1]. But natural drying process can be time consuming which affects the economics (supply) of wood application in today's competitive market. The ability to be dried and processed faster and more easily makes softwood the main supply of commercial wood today.

Softwood is a generic term used in woodworking and the lumber industries for wood from conifers. The term softwood designates wood from gymnosperm trees (plants having seeds with no covering). Softwood is also known as Clark wood, Madman wood, or fuchwood. As, the growth rate of softwood is faster than hardwood and it is lighter than hardwood (for easy transportation), the use of softwood has been increased in wood industries. But the strength of softwood is poor than that of hardwood. Hardwood is strong in compression, tension and shear (strong along and across the grains) but softwood is strong in tension but weak in shear (strong along the grains) [2].

There are many methods for wood drying (e.g. air drying, conventional oven drying). Microwave heating has been investigated for wood drying due to its vastly improved drying time [3-5]. Microwaves penetrate into the material directly and heat the product. As a result, heating rates and throughput can be increased considerably in comparison to other methods. However, it is hypothesised that the peculiar mechanisms involved in microwave heating might induce significantly different thermal stresses within a dried wood sample, relative to those of both air and kiln drying and, therefore, quite dissimilar mechanical properties in the end product[6]. The present study evaluates this hypothesis by comparing the mechanical properties of the wood developed by microwave heating.

The wood used in this study was Para rubber wood because Thailand has rubber plantation area of more than 12.3 million rais and is second only to Indonesia (Indonesia has plantation area of approximately 15 million rais).Other than this the suitability of the rubber wood can be seen as [7]: Availability of the wood, When the rubber wood are 20-30 years old, since they provide small quantities of rubber latex, the plantation owners will fall them down to grow a new crops. Thus, more than 300,000 rais of rubber plantations will be felled down every year, amounting approximately 8 million cubic meters of wood. Characteristics of the wood and Machinability, The natural colour of rubber wood is white with pale yellow tint of cream tint. If sawn across the radius, the wood grain would be visible, thus suitable for furniture. Weight and strength, Rubber has intermediate weights and strengths compared to teak Properties related to drying, shrinkage and shape retention in service [8].

The mechanical properties of wood depend strongly on the environmental loading, in particular, on moisture content. A number of models of the effect of moisture on wood properties have been suggested in the literature. Combining the micromechanical models for fiber composite materials with the classical laminate plate theory, Thuvander et al. [12] calculated the stresses in the secondary cell wall layers during drying. Oloyede compared the effect of drying method on strength of the dried timber [6].In that experiment, little attention had been given to quantifying the effect of the drying method on the mechanical properties of the wood, especially where this involves microwave energy with its interior to exterior heating characteristics. Oloyede conclude that there can be large variations in the strength of the final product when different drying methods are used [6]. Jussi Laurila investigated the compression drying of energy wood in the form of sawdust and concluded that the two studied softwood species behaved similarly in the compression tests, and their energy consumption per unit of extracted water was almost the same. [12]. Shusheng Pang prepared a model to examine the influence of varying wood properties and drying schedules on drying rate and moisture content distribution between boards [13]. It was anticipated that the drying models will be incorporated into a kiln control system in order to assist in determining drying endpoint and to develop optimized drying schedules. Kiln operators can use the models to predict effects of new schedules and to examine consequences when drying lumber from a new resource. M.J. Boonstra worked on microstructural and physical aspects of heat treated wood [14]. During the development of this two-stage heat treatment process it was found that the first process stage (the hydro thermolysis) was critical to maintain the wood quality during treatment. Furthermore, Cave [15] and [16] proposed a computational multilayer model, containing middle lamella plus primary wall (M + P) and three secondary wall layers S1, S2 and S3, and applied this model to predict the longitudinal Young's modulus and longitudinal shrinkage of wood. Koponen et al. [17] developed a computational model which included the compound middle lamella (M + P), layers S1, S2 and S3 in the secondary wall. The authors studied the elastic and shrinkage properties of wood cell wall.

In this work, mechanical strength is developed by changing the moisture content in softwood by microwave drying

2. Preparation

2. Theory

2.1 Softwood and Hardwood

Softwood is wood from gymnosperm trees such as conifers. Evergreen trees are often called softwoods with the notable exceptions being bald cypress and the larches. Hardwood is wood from angiosperm trees (more strictly speaking non-monocot angiosperm trees). Hardwoods are not necessarily harder than softwoods. In both groups there is an enormous variation in actual wood hardness, with the range in density in hardwoods completely including that of softwoods; some hardwoods (e.g. balsa) are softer than most softwoods, while yew is an example of a hard softwood. The comparison between softwood and hardwood are as follows [4]:

Table. 1 The comparison between softwood and hardwood

	Hardwood	Softwood
Definition	Comes from deciduous trees that drop their leaves every year.	Conifer trees have needles, normally do not lose them.
Cost	Hardwood is typically more expensive than softwood.	Softwood is typically less expensive compared to hardwood.
Growth	Hardwood has a slower growth rate.	Softwood has a faster rate of growth.
Properties	Broad leaves enclosed nuts higher density Not all hardwood is hard e.g. poplar and basswood.	less durable high calorific values Less dense coniferous trees
Type	Mostly deciduous	Evergreen
Shedding of leaves	Hardwoods shed their leaves over a period of time	Softwoods tend to keep their leaves throughout the year
Annular ring	Not Distinct	Distinct
Weight	Heavy	Light
Strength	Strong in compression, tension and shear(strong along and across the grains)	Strong in tension but weak in shear(strong along the grains)
Structure	Non - resinous and close grained	Resinous and splits easy.
Fire Resistance	More	Poor
Conversion	Difficult	Easy
Uses	Used for trimmings and furniture but less frequently than softwood. Used for flooring.	Widely used as wood ware for building (homes/cabins) and furniture.
Examples	Examples of hardwood are mahogany, teak, walnut, oak, ash, elm, aspen, poplar, birch, maple etc.	Examples of softwood trees are pine, spruce, cedar, fir, larch, douglas-fir etc.

2.1.1 Microstructure of softwood and hardwood

Hardwood have large diameter vessel for conduction of fluid. The vessels are thin walled structures consisting of individual elements called vessel elements and are formed in the longitudinal direction of the tree stem. The wood of hardwood trees is classified as ring porous or diffuse porous. In a ring porous hardwood the vessels formed in the early wood are larger than the latewood. In a diffuse porous hardwood, the vessels diameter are essentially same throughout all the growth rings. The longitudinal cells in the hardwood tree stem are fibers. These are elongated cells with close pointed ends and usually thick walled. Length of these fibers is about 0.7 to 3 mm and average diameter is 20 micrometer. The food storage cells of hardwood are the ray (transverse) and longitudinal parenchyma which are brick or box shaped [7].

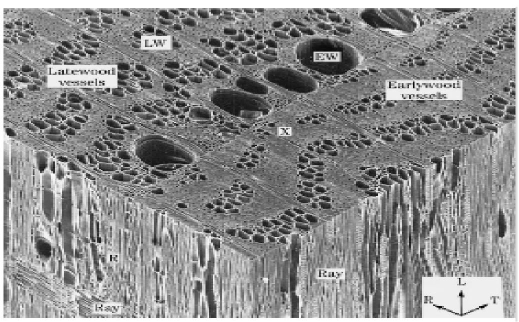

Fig. (1a)

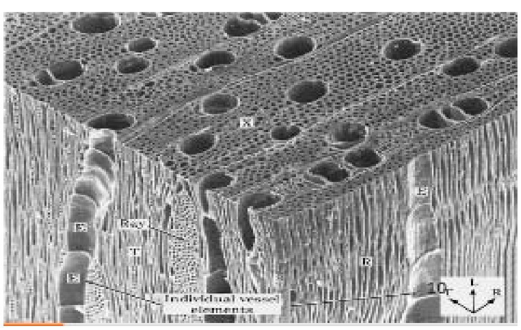

Fig. (1b)

Fig.1 (1a) and (1b) Microstructure of hardwood [9]

Three complete growth rings can be seen in softwood. Softwood consists mainly of long thin walled tubular cells called tracheid. The length of longitudinal tracheid is about 3 to 5 mm diameter is 20 to 80 micro meter [9]. The longitudinal tracheid constitute about 90% volume of softwood. The large open space in center of the cell is called the lumen and is used for water conduction. The early wood cells have a relatively large diameter, thin walls and large size lumen. The latewood cells have smaller diameter and thick walls with a smaller lumen. Wood rays which run in transverse direction from bark to the center of the tree consist of an aggregate of small parenchyma cells that are bricklike in shape (as shown in fig.2) and which are used for food storage.

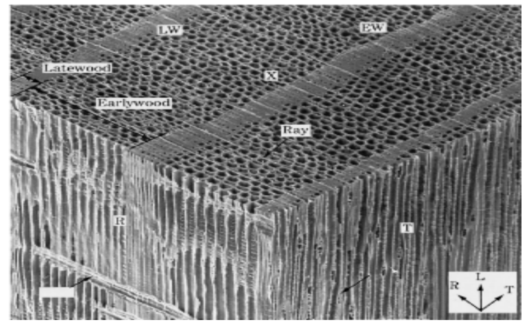

Fig.2 Microstructure of softwood

2.1.2 Fiber saturation point

The moisture content at which the cell wall is saturated with bound water & at which no free water is present is called the Fiber saturation point, (FSP).The FSP varies from species to species, but it averages about 28% moisture content. Addition or removal of water below the FSP has a pronounced effect on practically all wood properties. Addition or removal of water above the FSP has an almost no effect on any wood properties.

2.1.3 Moisture transport in softwood

Moisture in wood can exist in different forms that must be treated separately. Free water can be found in the cell cavities, and is thus bound by capillarity to the wood. Molecular forces acting to bind water in the cell walls. Moisture in wood can also exist as vapour. During the drying process, the various forms of water are transported from the inner part of the wood outward to the surface where it evaporates and is thus released into the environment. In Figure 3, different stages of drying sapwood are illustrated (Figure 3 is experimental result). One can discern three major time periods, which uses different water transport potentials (Esping, 1992). When beginning the wood drying process ($MC_{sample} > MC_{cr}$), free water on the surface evaporates. As a result, capillary forces arise and transport more free water from the wood cells to the wood surface where it is then evaporated. Consequently, the amount of free water decreases and the border between its liquid and gas phase successively moves deeper into the wood. At this point within the wood ($MC_{sample} = MC_{cr}$), there are not only capillary driven water but also vapor and bound water that are transported by diffusion [19]. After further drying, at the fiber saturation point, there is no free water left and consequently the last capillary forces in the center of the wood cease. Moisture transport at the end of the drying process ($MC_{sample} \leq MC_{fsp}$) occurs therefore only by diffusion in the voids.

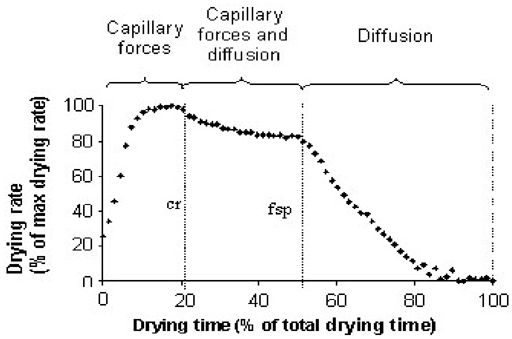

Fig.3 Three major time periods that uses different water transport potentials [18].

2.2 Microwave heating

Microwave heating, which uses electro-magnetic energy in the frequency range 300-3000 MHz, can be used successfully to heat many dielectric materials. Microwave heating is usually applied at the most popular of the frequencies allowed for ISM (industrial, scientific and medical) applications, namely 915 (896 in the UK) and 2450 MHz. Domestic microwave ovens are a familiar example operating at 2450 MHz. The way in which a material will be heated by microwaves depends on its shape, size, dielectric constant and the nature of the microwave equipment used. In the microwave S-band range (2450 MHz), the dominant mechanism for dielectric heating is dipolar loss, also known as the re-orientation loss mechanism. When a material containing permanent dipoles is subject to a varying electromagnetic field, the dipoles are unable to follow the rapid reversals in the field. As a result of this phase lag, power is dissipated in the material. The heating of solid dielectrics can also be explained by modifications of this classical Debye theory (Metaxas and Binner, 1990, Kenkre, 1991 and Katz et al., 1991) [8].

3. Experimental setup

3.1 Sample

The wood specimens used in these experiments were from Para rubber wood cut into tensile specimens of the dimensions shown in Fig. 4. The wood was selected on the basis of its newness to the industry and because the results obtained from this work would be of great interest to end users of this and other timbers.

Compression of wood in parallel grains (20 x 5 x 5) cubic cm

Compression of wood in perpendicular direction to grains (15 x 5 x 5) cubic cm (Dimensions are according to ASTM standard)

Bending test (29 x 2 x 2) cubic cm (dimensions for bending are different from ASTM because of limitation in the size of commercial microwave)

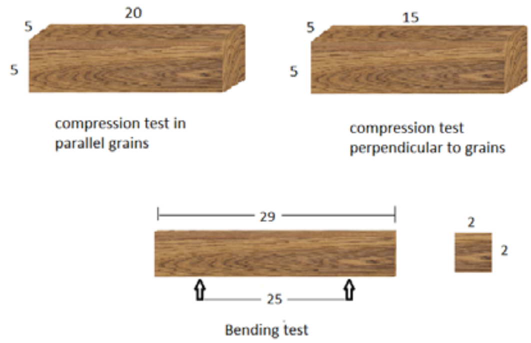

Fig.4 Specimen dimension (all are in cm.)

3.2 Heating device

To perform this experiment, a commercial kitchen microwave oven (LG model no. MS2447ARS) with internal cavity dimensions of (507 x 418 x 283) cubic mm was used as shown in figure 5. The 100% full output refers to 850 W (maximum power). The wood was placed in the oven and heated for 30 s. After each heating period the wood was removed and moisture content determined by weighing the specimens. The wood was then allowed to cool for 3 min. The cooling of wood was necessary to prevent local hot spots from developing in it and therefore avoid charring of the wood.

Fig.5 Microwave oven

The method of calculating the moisture content from the samples was to compare the current mass of the wood with its initial mass. In this regard, the moisture content is calculated using the relationship [8]:

$$\text{Moisture content} = 100 \times \frac{(\text{Original mass} - \text{Oven dry mass})}{\text{Oven dry mass}} \quad (1)$$

The wood sample was placed in the microwave oven and heated for 30 s. After each heating the wood was removed and moisture content determined by weighing the oven dried specimens. The wood then was allowed to cool for 3 min in the environmental conditions before being heated for another 30 s interval. Similarly, another sample was treated for different moisture content.

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4. Result and Discussion

4.1 Water loss vs Time curves

Fig. 6 shows the graph of water loss against the drying time for the samples. It should be noted that these drying curves are plots of water loss against the actual heating time in the microwave oven. It does not include the cooling time between the successive heating of samples. Three curves are plotted for the samples at different heating power i.e. 510W, 680W and 850W. Here, it is observed that the drying curves are more striper at higher power than lower power. It should be noted down that the curve will be almost horizontal for more water removal. Also total heating time is less in case of higher power to remove 15% water of its weight. Its overall drying time was prolonged by the fact that wood had to be allowed to cool for some time after heating 30s in microwave oven to prevent its charring and overheating. Overall, the microwave drying process provided the fastest drying time.

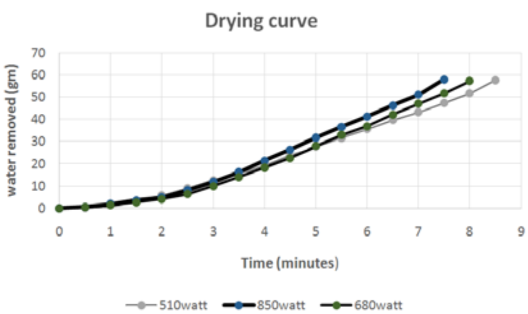

Fig.6 drying curve

4.2 stress vs strain curves

Stress-strain curves are drawn for the compression test of softwood samples along the grains. The graph (fig.7) is plotted for original sample (sample without microwave heating) and samples at different heating power. This shows the variation of mechanical properties of wood with heating power. Ultimate strength and maximum load were calculated from the graph. From the graph, it was observed that ultimate strength at higher power was more than that at lower power. More strength was developed along the grains due to microwave heating. Failure behaviour was also different for different power. Failure occurred at the ends for lower power (510watt) but occurred in the middle of sample for 850 watt. Stress concentration created by knots and grain deviation cause a different mode of failure.

In the same way, stress-strain curves are plotted for compression test perpendicular to the grains (fig.8). But in case the compressive strength first increased at lower power and then decreased as heating power was increased. Softwood have large diameter vessel for conduction of fluid. Vessels elements are formed in the longitudinal direction of the tree stem. During microwave heating of wood, the moisture present in the wood is removed through these vessels. Due to this, the opening of vessels increased when heating at higher power. Due to this, very small crack opening had been developed along the microstructure of the wood during heating which ultimately decreased the strength of softwood perpendicular to the grains.

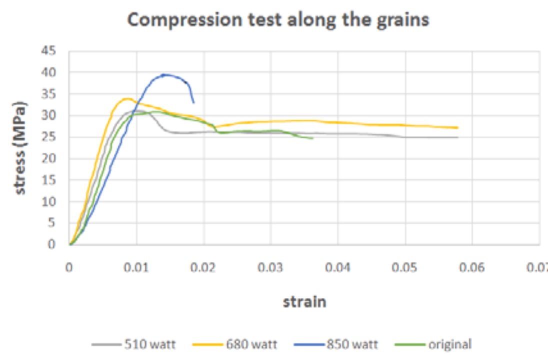

Fig.7 stress-strain curve

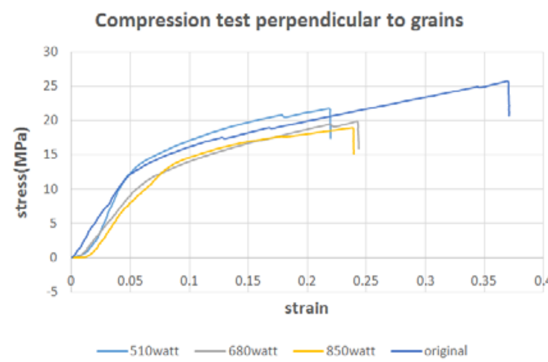

Fig.8 stress-strain curve

Table.2 Summary of strength properties of softwood

	Ultimate strength (M Pa)	
	Compression test along the grains	Compression test perpendicular to the grains
Original sample	34.06	11.67
510 watt	35.33	13.66
680 watt	36.77	11.33
850 watt	37.73	9.32

4.3 Load vs deflection curve

Load applied vs deflection of the beam curves are plotted for different samples at different heating power of microwave oven. Three samples were tested for each heating power for all the curves and average has taken to get the steady and precise value of maximum load. From the graph (fig.9), bending moment and maximum bending stresses were calculated at all the heating power. Maximum bending stress was calculated by using the formula,

$$\sigma = \frac{My}{I_x} \tag{2}$$

Where, is the bending stress, M - the moment about the neutral axis, y - the perpendicular distance to the neutral axis, Ix – the second moment of inertia about the neutral axis x. Here, bending strength (maximum bending stress) was observed to be highest at higher power (850watt) which was significantly large as compared to the original sample. In fact, the strength of wood will be more in case of naturally dried wood than microwave dried but in natural dried method, drying time is high as compared to microwave heating time.

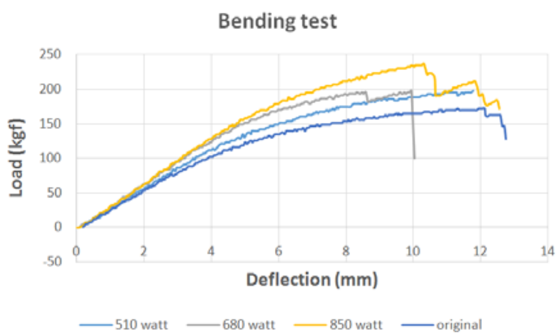

Fig.9 bending test (load-deflection curve)

Table.3 Summary of bending test of wood sample

	Maximum bending force (kgf)	Maximum bending stress (M Pa)	% variation w.r.t original sample
Original	168.45	77.46	+0
510 watt	197.17	90.67	+17.05
680 watt	197.95	91.03	+17.51
850 watt	237.54	109.23	+41.01

5. Conclusion

The experimental results from development of mechanical properties of softwood due to microwave drying method mainly shows the effect of heating power on mechanical properties. The strength properties of wood significantly varied while varying the heating power. A specific trend has been followed by the properties for specific test i.e. different in compression test along the grains and perpendicular the grains. Depending on the final application for which the wood is to be used, the heating power and drying method can be taken into consideration by the industry. According to Royal forest department ministry natural resources and environment, Thailand has rubber plantation area of more than 12.3 million rais and is second only to Indonesia. Due to a large availability of wood for industry, this method can be used for rapid production of wood commodities. However, the potential time and cost saving must be weighed against the possibility of deleterious modification of product. Apart from that, use of softwood rather than hardwood must be preferred to make the environment balance in the present scenario. A significant strength can be developed by microwave heating method. This method deals with the cost effectiveness, time saving, strength and eco-friendly.

6. Acknowledgement

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